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ABSTRACT

A selective literature review of overall system design considerations in the planning of information processing systems and networks. Specific topics include but are not limited to: (1) requirements and resources analysis, (2) problems of system networking, (3) input/output and remote terminal design, (4) character sets, (5) programming problems and languages, (6) processor design considerations, (7) advanced hardware developments, (8) debugging and on-line diagnosis or instrumentation and (9) problems of simulation. Supplemental notes and a bibliography of over 570 cited references are included. Parts 1 and 2 of this series on research and development efforts and requirements in the computer and information sciences are available as ERIC documents: LI 001 944 and LI 001 945 respectively. (Author/NH)

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Research and Development in the Computer and Information Sciences

Volume 3. Overall System Design Considerations— A Selective Literature Review

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Research and Development in the Computer and Information Sciences

3. Overall System Design Considerations
A Selective Literature Review

Mary Elizabeth Stevens

Center for Computer Sciences and Technology
National Bureau of Standards
Washington, D.C. 20234

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Foreword

The Center for Computer Sciences and Technology of the National Bureau of Standards has responsibility under the authority of Public Law 89–306 (the Brooks Bill) for automatic data processing standards development, for consultation and technical assistance to Federal agencies, and for supporting research in matters relating to the use of computers in the Federal Government.

This selective literature review is one of a series intended to improve interchange of information among those engaged in research and development in the fields of the computer and information sciences. Considered in this volume are the specific areas of overall system design considerations, including the problems of requirements analysis, system networking, terminal design, character sets, programming languages, and advanced hardware developments.

Names and descriptions of specific proprietary devices and equipment have been included for the convenience of the reader, but completeness in this respect is recognized to be impossible. Certain important developments have remained proprietary or have not been reported in the open literature; thus major contributors to key developments in the field may have been omitted.

The omission of any method or device does not necessarily imply that it is considered unsuitable or unsatisfactory, nor does inclusion of descriptive material on commercially available instruments, products, programs, or processes constitute endorsement.

LEWIS M. BRANSCOMB, *Director*

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Research and Development in the Computer and Information Sciences

3. Overall System Design Considerations: A Selective Literature Review

Mary Elizabeth Stevens

This report, the third in a series on research and development efforts and requirements in the computer and information sciences, is concerned with a selective literature review involving overall system design considerations in the planning of information processing systems and networks. Specific topics include but are not limited to: requirements and resources analysis, problems of system networking, input/output and remote terminal design, character sets, programming problems and languages, processor design considerations, advanced hardware developments, debugging and on-line diagnosis or instrumentation, and problems of simulation. Supplemental notes and a bibliography of over 570 cited references are included.

Key words: Data recording; debugging; holography; information control; input-output; integrated circuits; lasers; memory systems; multiprocessing; networks; on-line systems; programming; simulation; storage.

1. Introduction

This is the third in a planned series of reports involving selective literature reviews of research and development requirements and areas of continuing R & D concern in the computer and information sciences and technologies. In the first report,* the background considerations and general purposes intended to be served by the series are discussed. In addition, the general plan of attack and certain *caveats* are outlined.**

In the first two reports in this series, we have been concerned with *generalized* information processing systems as shown in Figure 1, more particularly these reports were concerned respectively with information acquisition, and sensing, and input operations and with information processing, storage, and output requirements. In this report we will be concerned with some of the overall system design considerations affecting more than one of the processes shown, such as programming languages, remote terminals used both for input and output, and advanced hardware developments generally.

Affecting all of the system design requirements for specific functions of generalized information processing systems are those of hierarchies and interaction of systems, and of effective access-response languages; the client, system-configuration, and system-usage considerations (especially in terms of multiple-access, time-shared systems), and of system evaluation, including such on-going "evaluations" as debugging aids and on-line instrumented checking or monitoring facilities.

Under overall system design requirements, we are concerned with input-output capabilities and terminal display and control equipment, with processor and storage systems design, with advanced technological developments, with programming language requirements, and with problems of on-line debugging, client protection, instrumentation, and simulation.

First, however, let us consider some of the overall system design considerations involved in requirements and resources analysis and in problems of system networking.

2. Requirements and Resources Analyses

The introduction of automatic data processing techniques has not changed the *kind* of fact-finding, analysis, forecasting, and evaluation required for effective systems planning and implementation; it has changed the *degree*, particularly with respect to extent, comprehensitivity, detail in depth, and questions of multiple possible interrelationships. For example, a "single information flow" concept [2.1] becomes realizable to an extent not possible before. On the other hand, distributed [2.2] and decentralized

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*Information Acquisition, Sensing, and Input: A Selective Literature Review.

**Appendix A of this report contains notes and quotations pertinent to the running text. For the convenience of the reader, notes "1.1" and "1.2" recapitulate some of the considerations discussed in the first report. Appendix B provides a bibliography of cited references.

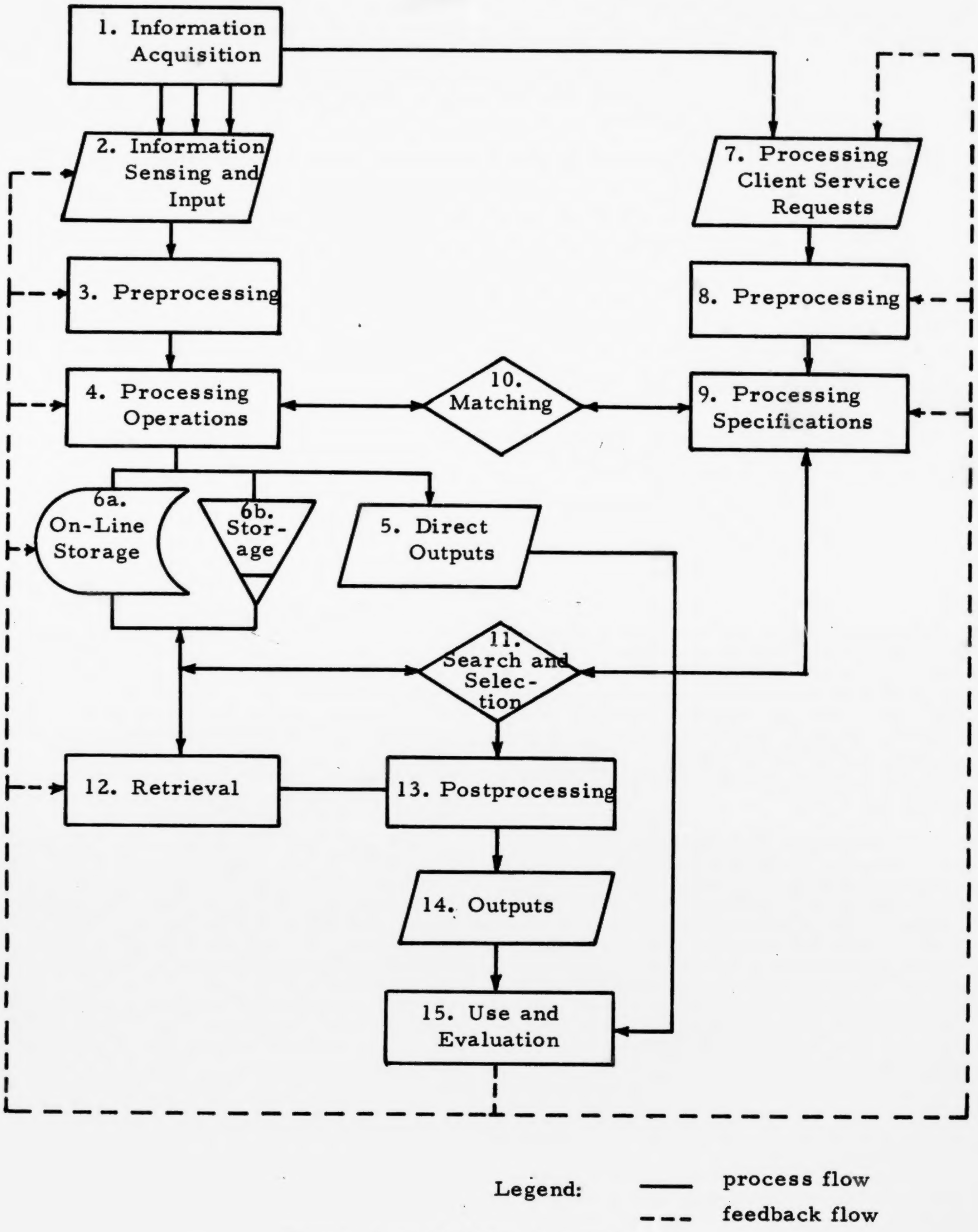
1. Information Acquisition
2. Information Sensing and Input
3. Preprocessing
4. Processing Operations
5. Direct Outputs
6a. On-Line Storage
6b. Storage
7. Processing Client Service Requests
8. Preprocessing
9. Processing Specifications
10. Matching
11. Search and Selection
12. Retrieval
13. Postprocessing
14. Outputs
15. Use and Evaluation
Legend:
process flow
feedback flow

FIGURE 1. *A generalized information processing system.*

systems also become more practical and efficient because of new possibilities for automatic control of necessary interactions.

A major area of continuing R & D concern with respect to both requirements and resources analysis is that of the development of more adequate methodologies.[2.3] Nevertheless, the new business on the agenda of the national information scene—that is, the challenge of system networking—offers new possibilities for a meshing of system design criteria that have to do with where and how the system is to be operated and with where and how it is to be used.

2.1. Requirements Analysis

Requirements analysis, as an operational *sine qua non* of system design, begins of course with suitable assessment of present and potential user needs. Elsewhere in this series of reports, some embarrassingly critical commentaries with respect to actual or prospective usage are selectively covered.[2.4] Assuming, however, that there are definitive needs of some specifiable clientele for processing system services that can be identified, we must first attempt some quantifiable measures of what, who, when, where, and why, the information-processing-system-service requests are to be honored.[2.5] In particular, improved techniques of analysis with respect to clientele requirements, information control requirements, and output and cost/benefit considerations are generally desired.

2.1.1. Clientele Requirements

It is noted first that "lack of communication between the client, that is, the man who will use the system, and the system designer is the first aspect of the brainware problem." (Clapp, 1967, p. 3). Considering the potential clients as individual users of an information processing system or service, the following are among the determinations that need to be made:[2.6]

1. Who are the potential users?
2. Where are they located?[2.7]
3. If there are many potential users, user groups, and user communities, how do needs for information and for processing services differ among them?[2.8]
4. What are the likely patterns and frequencies of usage for different types of potential clients?
5. To what extent are potential clients both motivated and trained to use the type of facilities and services proposed?[2.9]

However obvious these and other requirements analysis considerations may be, a present cause of critical concern is the general lack of experimental evidence on user reaction, user behavior, and user effectiveness.[2.10]

2.1.2. Information Control Requirements

Detailed consideration and decision-making with respect to controls over the quality and the quantity of information input, flow, processing, storage, retrieval, and output are essential to effective system design. Davis in a late 1967 lecture discussed many of the multifacetted problems involved in information control—in both system planning and system use. The varied aspects range from questions of information redundancy in information items to be processed and stored to those of error detection and correction with respect to an individual item record as received, processed, stored, and/or retrieved.

Among these information control requirements are: input and storage filtering and compression; quality control in the sense of the accuracy and reliability of the information to be processed in the system; questions of file integrity and the deliberate introduction of redundancy; problems of formatting, normalization, and standardization, and error detection and error correction techniques.

More particularly, Davis (1967) is concerned with problems of information control in a system with the following characteristics:

"1. It has several groups of users of differing administrative levels.
"2. The information within the system has imposed upon it varying privacy, security and/or confidentiality constraints.
"3. The information entering the system is of varying quality with respect to its substantive content; that is, it may be raw or unevaluated, it may have been subjected to a number of evaluation criteria or it may be invariant (grossly so) as standard reference data.
"4. The user audience is both local and remote.
"5. Individual users or user groups have individual access to the information contained within the system.
"6. The information within the system is multisource information."

(Davis, 1967, p. 1–2).

We may note first the problems of controls that will govern the total amount of information that is to be received, processed, and stored in the system. These may consist of input filtering operations[2.11] as in sampling techniques applied to remote data acquisition processes[2.12] or in checking for duplications and redundancies in the file.[2.13]

Other information control requirements with respect to the total amount of information in the system relate to problems of physical storage access, withdrawals and replacements of items to and from the store, maintenance problems including questions of whether or not integrity of the files must be provided (i.e., a master copy of each item accessible at all times),[2.14] provisions for the periodic purging of obsolete items,[2.15] revisions of the file organization in accordance with changing patterns of usage,[2.16] response requirements,[2.17] and requirements for display of all or part of an item and/or indications of its characteristics prior to physical retrieval.[2.18]

Another important area of information control is that of identification and authentication of material entering the system, with special problems likely to be involved, for example, in the dating of reports. (Croxton, 1955). As Davis (1967) also points out, the timeliness of information contained in the system depends not only on the time of its input but also upon the date or time it was recorded or reported and the date the information itself was originally acquired, including the special case of the "elastic ruler" (Birch, 1966).[2.19] Another typical problem is that of transliterations and transcriptions between items or messages recorded in many different languages.[2.20]

A crucial area of R & D concern is that of the accuracy, integrity, and reliability of information in the system, although these questions are all too often neglected in system design and use.[2.21] Again, Davis emphasizes the importance of information *content* controls. These may be achieved, on input, either by error-detecting checks on quantitative data or by "correctness control through 'common sense' or logical checks." (Davis, 1967, p. 10.)[2.22] Thus, the use of reliability indicators and automatic inference capabilities may provide significant advantages in improved information handling systems in the future.[2.23]

One of the obvious difficulties in controlling accuracy and reliability of the information content of items in the system is that of correction and updating cycles.[2.24] More commonly, however, errors affecting the accuracy and reliability of information are those of human errors in observation, recording, or transcription and those of transmission or equipment failure during communication and input. The incidence of such errors is in fact inevitable and poses a continuing challenge to the system designers which becomes increasingly severe as the systems themselves become more complex.[2.25]

It is to be noted, of course, that a major area of R & D concern in the communication sciences is that of information theoretic approaches to error detection, correction, and control. In terms of generalized information processing systems, however, we shall assume that advanced techniques of message encoding and decoding are available to the extent required, just as we assume adequate production quality controls in the manufacture and acceptance testing of, say, magnetic cores. Thus our concern here is with regard to the control, detection, and (where feasible), correction, of errors in information content of items in an information processing system or network, regardless of whatever protective encoding measures have been employed.

It should be recognized first of all that any formulation of an information-carrying message or record is an act of reportage, whether it is performed by man or by machine. Such reportage may itself be in error (the gunshots apparently observed during riot conditions may have been backfiring from a truck, the dial indicator of a recording instrument may be out of calibration, and the like). The recording of the observation may be in error: misreading of, say, the dial indicator, transposition of digits in copying a numerical data display, and accidental or inadvertent misspellings of names are obvious examples.

With respect to errors introduced by transmission, examples of R & D requirements and progress were cited in the first report in this series ("Information Acquisition, Sensing, and Input", Section 3.4). Two further examples to be noted here include the discussion by Hickey (1966) of techniques designed to handle burst-type errors[2.26] and a report by Menkhaus (1967) on recent developments at the Bell Telephone Laboratories.[2.27] For checking recording and/or transmission errors, a variety of error detection devices (such as input interlocks,[2.28] parity information,[2.29] check digits,[2.30] hash totals,[2.31] format controls and message lengths[2.32]) have been widely used.[2.33]

Problems introduced by alphanumeric digit transpositions or simple misspellings can often be attacked and solved by computer routines, *provided* that there is some sort of master authority list, or file, or the equivalent of this in terms of prior conditional matching.[2.34] For example, Alberga (1967) discusses the comparative efficiency of various methods of detecting errors in character strings.

The use of contextual information for error detection and possible correction in the case of automatic character recognition processes has been noted in a previous report in this series, that on information acquisition, sensing, and input. This is, of course, a special case of misspelling.[2.35] Some of the pertinent literature references include Edwards and Chambers (1964), Thomas and Kassler (1967) and Vossler and Branston (1964). The latter investigators, in particular, suggest the use of lookup dictionaries specialized as to subject field and analysis of part-of-speech transitions.[2.36]

Context analysis is important, first, because for the human such capabilities enable him to *predict* (and therefore skim over or filter out) message redundancies and to decide, in the presence of uncertainties between alternative message readings, the most probably correct message contents when noise, errors, or omissions occur in the actual transmission of the message.[2.37]

Context analysis also provides means for automatic error detection and error correction in the input of text at the character level, the word level, and the level of the document itself such as the detection of changes in terminology or the emergence of new content in a given subject field. For example, "various levels of context can be suggested, ranging from that of the characters surrounding the one in question to the more nebulous concept of the subject class of the document being read." (Thomas and Kassler, 1963, p. 5). In automatic character recognition, in particular, consideration has been given to letter digrams, trigrams, and syllable analysis approaches[2.38] as well as to dictionary lookups.

Special problems, less amenable to contextual considerations, arise in the case of large files containing many names (whether of persons or of drugs, for example) which are liable to misspellings or variant spellings or which are homonymous.[2.39] Information control requirements in such cases may involve the use of phonetic indexing techniques[2.40] as well as error detection and correction mechanisms.[2.41]

Automatic inference and consistency checks may be applied to error detection and error correction as well as to identification and authentication procedures. Waldo and DeBacker (1958) give an early example as applied to chemical structure data.[2.42] A man-machine interactive example has been described by North (1968).[2.43] For the future, however, it can be predicted that: "Ways must be found for the machine to freely accept and use incomplete, qualitative information, to mix that information with internally-derived information, and to accept modifications as easily as the original information is accepted." (Jensen, 1967, p. 1–1).

Finally, we note that, in its broadest sense, the term "control" obviously implies the ability to predict whether a given machine procedure will or will not have a solution and whether or not a given computer program, once started running, will ever come to a halt. The field of information control may thus include the theories of automata, computability, and recursive functions, and questions of the equivalence of Turing machines to other formal models of computable processes.

2.1.3. Other System Design Requirements

Other system design considerations with respect to requirements analysis include questions of centralization or decentralization of functions and facilities, including compromises such as clusters;[2.44] questions of batch-processing as against time-sharing or mixtures of these modes,[2.45] and questions of formatting, normalization,[2.46] and standardization.[2.47]

A final area of requirements analysis involves the questions of system design change and modification[2.48] and of system measurement.[2.49] In particular, information on types of system usage by various clients provides the basis for periodic re-design of system procedures and for appropriate re-organization of files. Such feedback information may also provide the client with system statistics that enable him to tailor his interest-profile or search strategy considerations to both the available collection characteristics and to his own selection requirements. As Williams suggests,[2.50] this kind of facility is particularly valuable in systems where the client himself may establish and modify the categories of items in the files that are most likely to be of interest to him.

2.2. Resources Analysis

Collateral with comprehensive analyses of potential system clienteles, their needs and requirements, their locations and the probable workloads (both as to types and also as to throughputs required), are the necessary analyses of the resources presently or potentially available. Resources analysis typically involves considerations of manpower availabilities, technological possibilities, and alternative procedural potentialities.

The question may well be raised with respect to an obvious spectrum of R & D requirements. Certainly there will be continuing areas of R & D concern with respect to advanced hardware technologies in processor and storage system design, and in materials and techniques that are related to these requirements. Next there are problems of "software"—that is, of programming techniques to take full advantage of parallel processing capabilities, associative memory accessing and organization, multiprogrammed and multiple-access system control.

Certain requirements are obviously overriding because they permeate the total system design and because they interact with many or all of the sub-systems involved. These include the problems of comparative pay-offs between various possible assemblies of hardware and software, the questions of programming languages and of suitable hierarchies of such languages, and the problems of man-machine interaction especially in the case of time-shared or multiple access systems.

Similarly, the requirements for handling a variety of input and output sensing modalities and for processing more than one I–O channel in an effectively simultaneous operation clearly indicate needs for continuing research and development efforts in the design and use of parallel processing techniques, multi-processor networks, time-shared multiple access scheduling, and multi-programming.

Hierarchies of languages are implied, ranging from those in which the remote console user speaks to the machine system in a relatively natural language (constrained to a greater or lesser degree) to those required for the highly sophisticated executive control, scheduling, file protection, accounting, monitoring, and instrumentation programs. For the future, increasing consideration needs to be given not only to hierarchies of languages for using systems, but to hierarchies of systems as well.[2.51]

There are, of course, concurrent hardware research, development, and effective usage requirements in all or most of these areas. Improvements in microform storage efficiency, lower per bit information-representation costs, communication channel utilization economies, improved quality of facsimile reproduction and transmission of items selected or retrieved, are obvious examples of directly foreseeable future demands. Some of the above considerations will be discussed in later sections of this report. Here we are concerned in particular with resources analysis in terms of system modularity, configuration and reconfiguration, and with provisions for safeguarding the information to be handled in the system.

2.2.1. System Modularity, Configuration, and Reconfiguration

Today, in increasingly complex information processing systems, there are typically requirements for considerable modularity and replication of system components in order to assure reliable, dependable, and continuous operation.[2.52] The possibilities for the use of parallel processing techniques are receiving increased R & D attention. Such techniques may be used to carry out data transfers simultaneously with respect [2.53] to the processing operations, to provide analyses necessary to convert sequential processing programs into parallel-path programs,[2.54] or to make allocations of system resources more efficiently because constraints on the sequence in which processing operations are executed can be relaxed.[2.55]

In terms of system configuration and reconfiguration, there is a continuing question of the extent of desirable replication of input-output units and other components or sub-assemblies. This may be particularly important for multiple-access and multiple-use systems.[2.56] A particularly important system configuration feature desired as a resource for large-scale information processing systems is that of open-endedness.[2.57]

System reconfigurations, often necessary as changing task orders are received, are particularly important in the area of shifting the system facilities for system self-checking and repair.[2.58] Thus Amdahl notes that "the process of eliminating and introducing components when changing tasks is reconfiguration. The time required to reconfigure upon occurrence of a malfunction may be a critical system parameter," (Amdahl, 1965, p. 39) and Dennis and Glaser emphasize that "the ability of a system to adapt to new hardware, improved procedures and new functions without interfering with normal system operation is mandatory." (Dennis and Glaser, 1965, p. 5.)

2.2.2. Safeguarding and Recovery Considerations

A first and obvious provision for "fail-safe" (or, more realistically, "fail-softly") [2.59] operation of an information processing system network is that of adequate information controls (for example, as discussed above) on the part of all member systems and components in the network.[2.60] This requirement reflects, of course, the familiar ADP aphorism of 'garbage in, garbage out'. Again, the total system must be adequately protected from inadvertent misuse, abuse, or damage on the part of its least experienced user or its least reliable component. Users must be protected from unauthorized access and exploitation by other users, and they also must be protected from the system itself, not only in the sense of equitable management, scheduling, and costing but also in the sense that system failures and malfunctions should not cause intolerable delays or irretrievable losses.[2.61]

Tie-ins to widespread communication networks and the emergence of computer-communication networks obviously imply some degree of both modularity and replication of components, providing thereby some measure of safeguarding and recovery protection.[2.62] An extensive bibliographic survey of proposed techniques for improving system reliability by providing various processes for introducing redundancy is provided by Short (1968).[2.63]

Protective redundancy of system components is, as we have seen, a major safeguarding provision in design for high system reliability and availability.[2.64] In terms of continuing R & D concerns, however, we note the desirability of minimizing the costs of replication [2.65] and the possibilities for development of formal models that will facilitate the choice of appropriate trade-offs between risks and costs.[2.66]

Finally, there are the questions of resources analysis with respect to the safeguarding of the *information* in the system or network—that is, the provisions for recovery, backup, rollback, and restart or repeat of messages, records, and files.[2.67] The importance of adequate recovery techniques in the event of either system failure or destruction or loss of stored data, can hardly be overestimated.[2.68]

The lessons of the Pentagon computer installation fire, in the early days of automatic data processing operations, still indicate today that, in many situations, separate-site replication of the master files (not only of data but also often of programs) is mandatory.[2.69] Otherwise, the system designer must determine whether or not the essential contents of the machine-usable master files can be recreated from preserved source data.[2.70] If the file contents can be recreated, then the designer must decide in what form and on what storage media the backup source records are to be preserved.[2.71]

In terms of system planning and resource analysis for information processing network design, we note the following questions:

> Can the network continue to provide at least minimal essential services in the case of one or more accidental or deliberate breaks in the links?
>
> What are the minimal essential services to be maintained at fail-safe levels? To what extent will special priorities and priority re-scheduling be required?
>
> Must dynamic re-routing of information flow be applied, or will store-and-forward with delayed re-routing techniques suffice?
>
> There are known techniques for evaluating optimum or near-optimum paths through complex paths in the sense of efficiency (economic, workload balancing, and throughput or timeliness considerations). Can these techniques be re-applied to the fail-safe or fail-softly requirements or must new methods and algorithms be developed?
>
> What are the fallback mechanisms at all levels and nodes of the system for: (a) specific failures

at a particular node, (b) breaks of one or more specific link(s), (c) massive failures, such as the New York area power blackout?

In general, with respect to areas of R & D concern affecting safeguarding and recovery provisions, we may conclude with Davis that "Rarely, if ever, are measurements made of the ability of the system to respond when partially destroyed or malfunctioning, of the length of time required for changing the system response to internal change in direction or to external stimuli, of the length of time necessary for a newcomer to be inserted into his assigned role in the system, of the redundancy, backup, or alternatives available at times of partial or total system destruction, and so forth. Clearly, there will be no adequately constructed system until such measures of effectiveness are understood and incorporated into system design." (Davis, 1964, p. 28).

3. Problems of System Networking

Steadily mounting evidence of the nearly inevitable development of information-processing-system networks, computer-communication utilities, and multiply-shared, machine-based, data banks illuminates a major and increasingly critical area of R & D concern. In this area, the problems of "organized complexity"[3.1] are likely to be at least an order of magnitude more intractable than they are today in multiprogrammed systems, much less in those systems requiring extensive man-machine interaction.

It is probable, in each of these three fields of development, that there has been and will continue to be for some time to come: (1) inadequate requirements and resources fact-finding and analysis,[3.2] (2) inadequate tools for system design,[3.3] and (3) the utter lack of appropriate means for evaluation *in advance* of extensive (and expensive) alternatives of system design and implementation.[3.4] Certainly the problems of system networking will involve those of priority scheduling and dynamic allocation and reallocation in aggravated form.[3.5] Moreover, the extensive prior experience in, for example, message-switching systems, is likely to be of relatively little benefit in the interactive system network.[3.6]

In particular, the practical problems of planning for true network systems in the areas of documentation and library services have scarcely begun to be attacked.[3.7] Nevertheless, the development of computer-communications networks has begun to emerge as the result of some or all of the following factors:

(1) Requirements for data acquisition and collection from a number of remote locations.[3.8]
(2) Demands for services and facilities not readily available in the potential user's immediate locality.
(3) Recognized needs to share data, programs and subroutines, work loads, and system resources.[3.9] In addition, various users may share the specialized facilities offered by one or more of the other members of the network.[3.10]

Similar requirements were considered by various major members of the aerospace industry as early as 1961, as follows:

"a. Load sharing among major computer centers . . .
"b. Data pick-up from remote test sites (or from airborne tests). In some cases real-time processing and retransmission of results to the test site would be desirable.
"c. Providing access for Plant A to a computer center at Location B. Plant A might have a medium-scale, small-scale, or no computer of its own.
"d. Data pick-up from dispersed plants and offices for processing and incorporation in overall reports. The dispersed points might be in the same locality as the processing center, or possibly as much as several thousand miles away." (Perlman, 1961, p. 209.)

Three special areas of system network planning may be noted in particular. These are the areas of network management and control, of distribution requirements, and of information flow requirements.

3.1. Network Management and Control Requirements

Effective provisions for network management and control derive directly from the basic objectives and mission of the network to be established. First, there are the questions with respect to the potential users of the system such as the following:

1. What are the objectives of the system itself? Is it to be a public system, free and accessible to all?[3.11] Is it to serve a spectrum of clientele interests, privileges, priorities, and different levels of need-to-know? Is it subject, in the provision of its services, to constraints of national security, constitutional rights (assurance of protection of the individual citizen's right to the security, among other things, of his "papers" from unreasonable searches and seizures), laws and regulations involving penalties for violation such as "Secrecy of Communications," and copyright inhibitions?
2. What are the charging and pricing policies, if any, to be assessed against different types of service, different types of clients, and

different priorities of service to the different members of the clientele?[3.12]

3. What different protections may be built into the system for different contributors with varying degrees of requirements for restrictions upon access to or use of their data?[3.13]
4. What are the priority, precedence, and interrupt provisions required in terms of the clientele?[3.14]

Next are the questions, in terms of the potential client-market, of the location, accessibility, cost, volume of traffic, and scheduling allocations for some determinate number of remote terminals, user stations, and communication links.

Then there are the questions of the performance and technological characteristics required with respect to these terminals, stations, and links.[3.15] Are the central system and the communication network both capable of handling, effectively simultaneously, the number of individual stations or links required? Does the communication system itself impose limitations on bandwidths available, data transmission rates, number of channels operable effectively in parallel? Are alternate transmission modes available in the event of channel usurpation or nonavailability for other reasons? Is effectively on-line responsiveness of the communication system linkages required and if so to what extent?

More generally, the following design and planning questions should be studied in depth if there is to be effective management and control:

“1. What is the scope of the network?
  a. Its geographical coverage
  b. Services to be provided by and to whom
  c. Location and facilities of participants
  d. Existing capabilities available
  e. Required rate of development
“2. What are the relevant software and data characteristics?
  a. Privacy requirements
  b. Accessibility and/or availability of program services
  c. System management programs
“3. What are the network management and control requirements?
  a. Standardization[3.16]
  b. Membership
  c. Information and program manipulation
  d. Feedback[3.17]
  e. Documentation
  f. Cost of services
“4. What are the pertinent legal regulations and practices?
  a. FCC regulations
  b. Carrier rate structure
  c. Common carrier use
  d. Responsibilities for information content
  e. Privacy versus broadcast methods
  f. Federal agency jurisdiction . . .
“5. What are the technological constraints?
“6. What are the budgetary constraints and financially allowable rate of development?”

(Davis, 1968, p. 4–5).

The factors of geographical coverage, location and facilities of participants, and membership point to some of the distribution requirements, to be considered next.

3.2. Distribution Requirements

A major area of concern with respect to distribution requirements in information processing network planning is that of the question of the type and extent of centralization or decentralization of the various system functions. There is first the possibility of a single master, supervisory, and control processing center linked to many geographically dispersed satellite centers (which carry out varying degrees of preprocessing and post-processing of the information handled by the central system) and terminals. Secondly, several interconnected but independent processors may interchange control and supervisory functions as workload and other considerations demand.[3.18] Still another possibility is regional centralization such has been recommended for a national documentation network, for example.[3.19]

Different compromises in network and system design to meet distribution requirements are also obviously possible.[3.20] However, a variety of special problems may arise with respect to distribution requirements when some of the network functions are decentralized.[3.21]

Then there is the question of whether or not the network is to be physically distributed—that is, “the term ‘distributed network’ is best used to delineate those communications networks based on connecting each station to *all* adjacent stations, rather than to just a few switching points, as in a centralized network.” (Baran, 1964, p. 5). This distribution requirement consideration is closely related to information flow analysis and planning, especially with respect to assurance of continuing productive operation when certain parts of the network are inoperative.[3.22] It should be noted, moreover, that “solving the data base management problem has been beyond the state of the art.” (Dennis, 1968, p. 373).

3.3. Information Flow Requirements

In general, it may be concluded that “to determine the correct configuration, certain basic factors must be investigated. These factors generally relate to the information flow requirements and include the following:

1. The kind of information to be transmitted through the communications network and the types of messages.

2. The number of data sources and points of distribution to be encompassed by the network and their locations.
3. The volume of information (in terms of messages and lengths of messages) which must flow among the various locations.
4. How soon the information must arrive to be useful. What intervals the information is to be transmitted and when. How much delay is permissible and the penalty for delays.
5. The reliability requirements with respect to the accuracy of transmitted data, or system failure and the penalty for failure.
6. How the total system is going to grow and the rate of growth."

(Probst, 1968, p. 19).

More specifically, overall system design considerations with respect to information flow requirements typically involve calculations of average daily volume of message and data traffic, peak loads anticipated, average message length, the number of messages to be transmitted in given time intervals, total transmission time requirements, and questions of variable duty cycles for different system and network components.[3.23]

Examples of relatively recent developments in this area include RADA (Random Access Discrete Address) techniques [3.24] and a "hot-potato" routing scheme for distributed networks.[3.25] A continuing R & D challenge in terms of scientific and technical information services has been posed by Tell (1966) by analogy with the techniques of input-output economics.[3.26] Of major concern is the problem of high costs of communication facilities necessary to meet network information flow requirements.[3.27]

4. Input-Output, Terminal Design, and Character Sets

The area of input-output, especially for two-dimensional and even three-dimensional information processing, is currently receiving important emphasis in overall information processing system design. One reason for this, as we have seen, is the increased attention being given to remotely accessed, time-sharing, or man-machine interaction systems. In particular, as noted by Tukey and Wilk: "The issues and problems of graphical presentation in data analysis need and deserve attention from many different angles, ranging from profound psychological questions to narrow technological ones. These challenges will be deepened by the evolution of facilities for graphical real-time interaction." (Tukey and Wilk, 1966, p. 705).

4.1. General Input/Output Considerations

Since a multiplicity of input and output lines are assumed for a variety of types of information to be processed (including feedback information from users and from the system itself), development requirements with respect to both equipment and sortware processing operations include batching of various input units, buffering of at least some types of input (as required, for example, to provide necessary reformatting), and multiplexing of input operations. Such considerations also apply even more forcefully to interfaces between the various nodes of a network involving more than one type of participating system.[4.2]

Format control is typically needed both into and out of the system, preferably under dynamic program control. The format control subsystem, by means of address storage registers or other techniques, should enable the input data itself to determine where it should go in storage, and other means of "self-addressing" should be provided without the need for elaborate or inefficient programming and related software requirements.[4.3]

The overall output capability design should provide ability to reformat conveniently and efficiently [4.4] as well as to select certain character sequences. Because of the variety of equipments needed for various tasks, provision should be made for reversal of the bit order of input and output data so that either high or low order bits can be processed first. In the case of displays, special provisions may be required to prevent overlapping of symbols.[4.5]

Related to format control is the question of variable byte size for input and output. For the future, system design will require ASCII (American Standard Code for Information Interchange) code sorting and ordering capabilities, but in many circumatances it will also be necessary to handle collapsed subsets of ASCII and other codes, longer byte lengths such as 10- and 14-bit codes for typesetting, and even longer codes for monotype, numeric process control, data logging, and equipment control.

Analog-digital and digital-analog convertibility is needed for experimental applications in source data automation, measurements automation, map analysis, map and contour plotting, pattern processing, and the like. One example of convergent efforts in the field is provided by Ramsey and Strauss (1966) who discuss interrupt handling in the area of hybrid analog-digital computers as representative of more general on-line scheduling problems. For some of these investigations, at least *virtual* real-time clocks will be needed.[4.6] This implies processor main frame and transfer trunks versatile enough to handle these requirements whether implemented by software or built into the hardware.

Another important requirement is for versatile and varied graphic input and output capability, including light pen, microfilm, FOSDIC-type scanning, mark-sensing, OCR (Optical Character Recognition), MICR (Magnetic Ink Character Recognition), color-code input (such as Lovibond color network), and three-dimensional probe data *in* (see the first report in this series), and large-vocabulary character and symbol generation; diagram retrieval, construction and reconstruction, and perspective or three-dimensional projection capabilities *out* (as discussed in the second report in this series). Photographic and TV-type input and output with good resolution, hard-copy reproduction capability, varying gray-scale facility, and at least the possibility of handling color input or output display techniques will be required in future system design.[4.7] Audio input-output capabilities should include dataphone, acoustic signal inputs, and voice, with speech compression on output, requiring controlled timing of "bursts" or "slices."

In many system design situations, we should be able to switch peripheral equipment configurations around for special purposes and we may need to have multiple access to various types of peripheral devices simultaneously during the same processing run, e.g., to be able to shift between character recognition and graphic scanning tasks for input of material where text and graphics are intermixed.

Related to these problems of input, output, and on-line responsiveness (especially for clients involved in problem-solving applications), is the concept of graphical communication generally.[4.8] This presupposes, first, a suitable language for the exchange of both pictorial data and control information between the designer and the machine, and secondly, provisions for the dynamic manipulation of data and controls.[4.9]

Recent programming techniques under investigation for the display of two-dimensional structure information are exemplified in work by Forgie,[4.10] by Hagan et al. (1968)[4.11], and at the University of Michigan (Sibley et al., 1968).[4.12] Then there is the DIALOG programming system developed at the ITT Research Institute in Chicago for graphical, textual, and numeric data input and display, online and off-line programming facilities, and hard-copy options. (Cameron et al., 1967). A special feature is a character-by character man-machine interaction mode, so that the programmer may use only those input symbols that are syntactically correct. For more efficient machine use in production-type operations, a DIALOG compiler for the IBM 7094 has been prepared following the "Transmographer" of McClure.[4.13] (McClure, 1965).

Then we note that "in the area of displays, determining the information to be displayed and generating the procedures for retrieval and formatting of the information are the difficult problems." (Kroger, 1965, p. 269). Further, as of today, "too many systems are designed to display all the data, and not to display only the data needed for the decisions the system is called upon to make." (Fubini, 1965, p. 2).

In general, the client of the on-line, graphical input-output, and problem-solving system needs convenient means for the input of his initial data, effective control of machine processing operations, effectively instantaneous system response, displays of results that are both responsive to his needs and also geared to his convenience, and handy means for the permanent recording of the decisions and design choices he has made.

With respect to these client desiderata, the identifiable R & D requirements relate to keyboard function key overlay design;[4.14] improvements in both problem-oriented and client-oriented languages for man-machine communication and interaction;[4.15] fast, high-resolution, flicker-free display generation;[4.16] ability to selectively emphasize various areas of display,[4.17] further development of the combination of static displays (such as maps) with computer-controlled dynamic displays,[4.18] and rapid responsivity of the system to feedback from the client.

Since remote, reactive terminals are an increasingly important factor in systems involving dynamic man-machine interaction, the question of design of remote inquiry stations and consoles necessarily raises problems of human engineering for whose solution there is inadequate experimental cost-benefit, and motivational data[4.19] available to date. Also involved are questions of acceptance and interactive response by the client to feedback outputs from the system, including requests for further information or additional inputs and display of re-processed results.

4.2. Keyboards and Remote Terminal Design

Where graphic input and output facilities are to be available to on-line users, there are unresolved questions of interrelated and interlocking system and human factors. How clumsy are light pens or pointers to use? Are they heavy or difficult to aim?[4.20] Should light-pen imputs be displayed a little to the left or to the right of the actual light-pen location so that the active part of the input is not blocked from view by the moving light-pen itself?[4.21] Can flicker-rate be kept to a tolerable level without undue and costly regeneration demands on a multiply-accessed central processor used by the many clients, or must the remote terminal have storage and display re-generation capabilities at added cost and design complexity?[4.22] For graphic input and display should the input surface be flat, upright, or slanted?[4.23]

It has been pointed out, in the case of the recent development of a solid state keyboard, that "the requirements of today's keyboards are becoming more complex. Increased reliability and more flexibility to meet specialized demands are essential. Remote terminals are quite often operated by relatively untrained personnel and the keyboard must be capable of error-free operation for these people. At the same time it should be capable of high thru-put for the trained operator as will be used on a key tape machine.

"Some of the limitations of existing keyboards are:

- Mechanical interlocks which reduce operator speed.
- Excessive service (increasingly important for remote terminals).
- Contact bounce and wear of mechanical switches.
- Non-flexible format." (Vorthmann and Maupin, 1969, p. 149).

For automatic typographic composition applications, it is emphasized that "the application of computers to typesetting only emphasizes the scope and the need for a radical re-thinking on keyset design," and that, although "one may imagine that the keyboard is a relatively simple piece of equipment . . . in fact, it presents a unique combination of mechanical, electrical and human problems." (Boyd, 1965, p. 152). Current R & D concerns with respect to keyboard *re*design involve consideration of principles of motion study as applied to key positioning, key shape, key pressures required, and the like.[4.24]

Nevertheless, it is to be emphasized that "input-output devices are still largely the result of an ingenious engineering development and a somewhat casual and often belated attention to operator, system attachment, and programming problems" and that ". . . no input-output device, including all terminals combined, has yet received the careful and competent human factors study afforded the cockpit of a military aircraft." [4.25] (Brooks, 1965, p. 89).

Beyond this are questions of design requirements for dynamic on-line display. Thus we are concerned with requirements for improved remote input console and terminal design.[4.26] Relatively recent input-output terminal developments, especially for remote consoles or dynamic man-machine interaction, have been marked by improved potentialities for two- and even three-dimensional data processing and by further investigation of prospects for color, as discussed, for example, by Rosa (1965),[4.27] Mahan (1968) [4.28] and Arora et al. (1967), among others. Van Dam (1966) has provided an informative state-of-the-art review of such scanning and input/output techniques. Vlahos (1965) considers human factor elements in three-dimensional display. Ophir et al. (1969) discuss computer-generated stereographic displays, on-line.[4.29]

In the area of input-output engineering and system design, what is needed for more effective man-machine communication and interaction will include the provision for remote consoles that are truly convenient for client use. Hardware, software, and behavioral factors are variously interrelated in terms of desired display and console improvements.[4.30]

The desirable design specifications for remote inquiry stations, consoles, and terminals and display devices as discussed in the literature variously include: economy, dependability, and small enough size for convenient personal use.[4.31] Some misgivings continue to be expressed on this score. Thus, it is reported that Project Intrex will consider the design of much more satisfactory small consoles [4.32] and Wagner and Granholm warn that "at the moment, it is difficult to predict whether remote *personal* consoles can be economically justified to the same extent that technological advances will make them feasible." (1965, p. 288). Cost certainly appears to be a major factor in the limited nature of the use that has been made of remote terminals to date.[4.33]

A second requirement is for the provision of adequate buffering facilities including, for at least some recent systems, capabilities for local display maintenance.[4.34] From the hardware standpoint, it is noted that "the major improvements in displays will be in cost and in the determination and implementation of the proper functions from the user standpoint. The cathode-ray tube will probably be dominant as the visual transducer for console displays through 1970, but there are several new techniques for flat-panel, digitally addressed displays presently under development that may eventually replace the CRT in many applications. The advances in memory and logic component technologolies will permit significant improvements in the logic and memory portions of console displays." (Hobbs, 1966, p. 37).

Other features that are desirable may include a capability for relatively persistent display, for example, up to several hours or several days,[4.35] and the capability, as in the Grafacon 1010 (a commercially available version of the RAND Tablet) for the tracing of material such as maps or charts to be superimposed on the input surface, or the Sylvania Data Tablet ET 1, which also allows a modest third axis capability.

As in the case of system outputs generally, hard-copy options are often desired through the terminal device. For example, the console "should have a local storage device on which the user can build up a file of the pieces of information he is retrieving, so that he can go back and forth in referring to it. It should have means of giving him low-cost hard copy of selected material he has been shown and temporarily stored." (King, 1965, p. 92).

The use of *markers* and *identifiers* for on-line text editing purposes should be simplified or eliminated to the maximum extent possible. If, for example, elaborate line and word sequence identifications must be used both by the machine system and by the client, then the virtues of machine processing for this type of application will be largely lost. Such systems should not only be easy to use, but easy to learn how to use.

An important question to be asked by the system designer is whether the output responses will be of the types and in the formats that the client will expect to receive. It is noted in particular that "the closer the correspondence of the computer output is to the methods of presenting textual and tabular material familiar to the user, the greater his information absorption rate will be." (Morenoff and McLean, 1967, p. 20). Thus, in engineering applications, for example, the client may want results to be displayed in a familiar format such as a Nyquist plot.[4.36] Similarly, in operations on files or data banks, the user should be able to structure and sequence files and subfiles for display and selection to suit his own purposes.[4.37]

For effective online operation, the system should provide responses within the reading rates of typical users, and with good resolution, little or no flicker, and with both upper and lower case.[4.38] A somewhat more specific and stringent list of remote terminal desiderata is provided by Licklider, with particular reference to the requirements of multiple access to the body of recorded knowledge. His desired features include, but are not limited to, color, or at least gradations of gray scale;[4.39] terse or abbreviated modes of expression to the machine with full or "debreviated" response;[4.40] selective erasibility of the display by either program or user command,[4.41] and capabilities such as the following: "Shortly thereafter, the system tells me: 'Response too extensive to fit on screen. Do you wish short version, multipage display, or typewriter-only display?'." (Licklider, 1965, p. 50). Another design criterion affected by the factor of client convenience is that of the extent of display on the console face of meta-information.[4.42]

Continuing needs for technological developments have also been indicated for improved terminal and output display design. Examples include the development of new, fast phosphors and other materials,[4.43] use of analog predictive circuitry to improve tracking performance,[4.44] and variable sequencing of processor operations in computation and display.[4.45] A number of advanced techniques are also being applied to large-screen displays,[4.46] although some continuing R & D difficulties are to noted.[4.47] Multiplexing of graphic display devices may also be required.[4.48]

Returning, however, to the human behavioral factors in input-output and terminal design, we note that man-machine relationships require further investigation both from the standpoint of human engineering principles and also from that of attitudes of clients and users,[4.49] that there are continuing requirements for research and development efforts on both sides of the interface[4.50] and that, in all probability, "industry will require more special prodding in the display-control area than in the other relevant areas of computer technology." (Licklider, 1965, p. 66).

We note further an area of R & D concern that will recur in many other aspects of information processing system design and use, and especially in information selection and retrieval applications. More specifically: "The major problem today in the design of display systems is that we cannot specify in more than qualitative terms such critical criteria as 'context' and 'meaning'." (Muckler and Obermayer, 1965, p, 36). Swanson adds: "Other restrictions derive from the need of programs to solve hidden line problems, to recognize context, and to make abstractions." (Swanson, 1967, p. 39).

Finally, we note the specific problem in documentary and library applications that large character repertoires are important to input and output representations of various levels of reference and emphasis in technical texts (especially, for example, in patent applications with multilevel referrals to accompanying drawings and diagrams) and to delineation of different types of possible access points in indexes and catalog cards.[4.51] In addition, a wide variety of special symbols and/or exotic alphabets are typically employed in texts dealing primarily with mathematical, logical or chemical subjects. A text written principally in one particular language and alphabet may frequently use the alphabet set of one or more other languages, as in reference to proper names, citations, and quotations.

4.3. Character Set Requirements

For multiple-access systems "most creative users want large character sets with lower-case as well as capital letters, with Greek as well as Latin letters, with an abundance of logical and mathematical signs and symbols, and with all the common punctuation marks." (Licklider, 1965, p. 182). In addition, subscripts, superscripts and diacritical marks may be required.[4.52]

Attacks on problems of character-set requirements for output begin with on-line printer variations to provide larger output character-set vocabularies at the expense both of output printing speed and of prior input precedence-coding and/or of processor programming. Larger character-set vocabularies are provided both by photocomposition techniques and by electronic character-generation methods, but again at the expense of either pre-coding or programming requirements.[4.53]

It should be noted, of course, that the internal language of most general-purpose information processing systems is limited to no more than 64 discrete characters, symbols, and control codes. Thus there must be extensive provision for multiple table lookups and/or for decoding and re-encoding of precedence codes or transformation sequences, on both input and output, if any internal manipulations are to be performed on the textual material. In general, the larger the character set, the more elaborate the precoding and/or programming efforts that will be required.

Then there is the problem of setting up keyboard character sets that are adequate for application requirements and yet within reasonable human engineering limitations. One proposed solution, the use of keyboard overlays and control codes to enable rapid shifting from one character subset to another, is exemplified by developments at Bunker-Ramo.[4.54] Another possible solution to the character set problem as related to human engineering factors that is receiving continuing R & D concern is to provide multiple inputs via a single keystroke, such as "chord" typewriters or Stenotype devices.[4.55]

Regardless of what may be available through various conversion, transliteration, or translation processes on either input or output, there remains the question of the effects of *internal* character set upon sorting, ordering, filing and interfiling operations for a specific processor-storage system. For example, "other control elements which are frequently required in the design of information systems are special sorting elements. In a directory of personal names, such as those which might be found in an author bibliography, if names beginning with 'Mc' and those beginning with 'Mac' are to sort together, then special sorting codes must be entered into the computer for this purpose." (Austin, 1966, pp. 243–244)[4.56]

The size of an adequate character set is a particularly critical problem in at least two significant areas: those of automatic typographic-quality typesetting and of library automation.[4.57] Complex character set requirements are also to be noted in such multiple-access applications as computer-aided-instruction (CAI).[4.58] Avram et al., considering automation requirements at the Library of Congress, stress that "keyboard entry devices must be designed to facilitate the input of a variety of languages and diacriticals." (1965, p. 4). These authors point out further that "if the problems associated with the design of input keyboards and photocomposition printing devices can be resolved for the multiplicity of alphabets, there still will remain the formidable task of searching in a machine file which contains them." (Avram et al., 1965, p. 89). Similarly, Haring (1968) points out that the 128 symbols provided in the ASCII code is inadequate for the augmented catalog under development at Project INTREX.[4.59]

The very number and diversity of varied but realistic cataloging, filing, and search considerations in terms of character-set and sort-order requirements that exist today may indeed surprise the typical computer scientist facing library automation implementation problems. Nevertheless, particular problems of sorting, filing, and reassembly orders in terms of practical usage needs and acceptability to the clients of mechanized systems and services should be subjects of concern to designers of machine languages, machine character-sets, and of the processors as such.[4.60]

The even more difficult case of extensive mathematical, chemical, and other special symbols desired on output imposes additional hardware requirements, whether for high speed printers, photocomposition devices, or character generators.[4.61] This, then, is the area that has been called "Caligraphy by Computer."[4.62] A final example of unusual character set requirements is provided by "Type-A-Circuit" developments.[4.63]

5. Programming Problems and Languages and Processor Design Considerations

The questions of design and development of appropriate programming languages and of processor design are obviously pertinent to all of the operations shown in Figure 1. As of 1967–68, however, special emphasis in terms of research requirements lies in three principal areas: user-oriented input, response and display languages; symbol manipulation languages capable of handling arrays of multiply interrelated data, and increasing interpenetration of hardware and software considerations in both system design and system use.[5.1]

For example, in the operations of developing processing specifications from client requests for service (Boxes 8 and 9 of Fig. 1), we need: new and more powerful problem-oriented languages; versatile supervisory, executive, scheduling, and accounting programs; hierarchies of programming languages; multiprogramming systems; improved microprogramming; new approaches to increasing interdependence of programming and hardware; and more versatile and powerful simulation languages.

The overall system design requirements of the future indicate R & D concerns with programming languages, and especially with hierarchies of such languages at the present time.[5.2] Controversies certainly exist as between advocates of more and more "universal" languages and proponents of problem-oriented or user-oriented machine communication techniques.

5.1. Programming Problems and Language

Continuing R & D requirements for programming language improvements represent two contradictory requirements: on the one hand, there is recognized need for increasingly universal, common-purpose languages compatible with a wide variety of systems, hardware configurations, and types of applications; and on the other hand for hierarchies of language systems. In addition, a number of special requirements for more flexible, versatile and powerful languages are just beginning to emerge, especially in such areas as graphical communication, on-line problem solving, multiple access and multiprocessor control systems, simulation, and on-line instrumentation.

We are concerned here, then, with general-purpose language and compatibility requirements; with special-purpose requirements such as problem-oriented programs, list-processing and other techniques for non-numeric data processing; with special problem areas such as very large programs and the requirements of multiple-access and multiprogrammed systems; with hierarchies of programming languages, and with the increasing interdependence of software and hardware considerations.

5.1.1. Problems of Very Large Programs and of Program Documentation

In terms of continuing R & D concern, we note first the problems of handling very large programs, defined as those that demand many times the available main storage capacity and that are sufficiently complex in structure to require more than ten independent programmers to work on them.[5.3] An obvious requirement is to develop efficient techniques for segmentation: "When many programmers are involved, there is the problem of factoring the system into appropriate subtasks. At the present time this is an art rather than a science, and very few people are good at its practice, because of the inability to find useful algorithms for estimating the size and degree of difficulty of programming tasks." (Steel, 1965, p. 234). The questions of *automatic* segmentation, although recognized as critical and difficult problems, have therefore been raised.[5.4]

In particular, the checkout of very large progrâms presents special problems.* For example, "another practical problem, which is now beginning to loom very large indeed and offers little prospect of a satisfactory solution, is that of checking the correctness of a large program." (Gill, 1965, p. 203). Further, "the error reporting rate from a program system of several million instructions is sufficient to occupy a staff larger than most computing installations possess." (Steel, 1965, p. 233).

Other specific requirements in the programming problem areas include improved provision for adequate program documentation and related controls.[5.5] For example, Pravikoff (1965) presents cogent arguments for the improved documentation for programs generally. Mills (1967) points to the special documentation problems in multiple access systems where users are less and less apt to be trained programmers.[5.6] Dennis (1968) points to the present high costs of large-scale programming efforts as due to inadequate documentation that prevents taking advantage of programming already achieved,[5.7] while Kay (1969) considers the advantages of on-line documentation systems.[5.8] Thus the area of program documentation requires further study and concern.

A related difficulty is that of inadequate means for translation between machine languages, although some progress has been made.[5.9] An intriguing possibility deserving further investigation has been raised by Burge (1966, p. 60) as follows: "Presented here is a problem and a framework for its solution. The problem is as follows: Can we get a computer program to scan a library of programs, detect common parts of patterns, extract them, and re-program the library so that these common parts are shared?"

Another current question of R & D concern with respect to programming problems is of the *generality* with which a given language system can or cannot cope with a wide variety of system configurations and reconfigurations over time.[5.10] The questions of development of more effective common-purpose or general-purpose languages involve very real problems of mutually exclusive features and of choices as between a number of means of achieving certain desirable built-in features.[5.11]

Areas of continuing R & D concern in programming language developments reflect, first, the need for increasing generality, universality, and compatibility (these objectives are followed in general-purpose language construction and standardization, on the one hand, and by increasing recognition of the needs for hierarchies of language, on the other); secondly, the special requirements of multiple-access, multiprogrammed, multiprocessor, and parallel processing systems; thirdly, requirements for problem-oriented and other special-purpose languages, and finally, needs for continuing advances in hardware-software balances and in fundamental programming theory.

5.1.2. General-Purpose Programming Requirements

The presently indicated transition from exclusively batch or job-shop operation to on-line, multiple access system management[5.12] sharply aggravates the problems of programming language requirements in a number of different ways. First, there are very real difficulties in translating from programming languages and concepts geared to sole occupancy and use of system facilities to those required in the multiple-access, and multiprogrammed, much less the multiprocessor and network environment.[5.13]

As Brooks (1965) points out: "Today's excitement centers chiefly around (1) multiprogramming for time-sharing, (2) multiple-computer systems using a few computers for ultra-reliability, and (3) multiple-computer systems using a highly parallel structure for specialized efficiency on highly structured problems."[5.14] In all of these cases, moreover, the R & D requirements are typically aggravated by a persistent tendency to underestimate the difficulties of effective problem solution.[5.15]

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*See also Section 7.1 of this report, on debugging problems generally.

An obvious first common-purpose requirement is for truly efficient supervisory, accounting, and monitoring control programs [5.16] that will effectively allocate and dynamically reallocate system resources, that will be secure from either inadvertent or malicious interference, and that will be flexible enough to accommodate to changing clientele needs, often with new and unprecented applications.[5.17]

Also in the area of general-purpose programming requirements are the various emerging programs for *generalized* file or data base management, maintenance, and use.[5.18] The first requirement, here, is for reconciliation of variable input, file storage, and output formats, together with flexible means for dupe checking on input, combinatorial selection, and output *re*formatting.[5.19] Closely related are the questions of the so-called "formatted file systems." [5.20]

A first approach to such general-purpose programming systems was undoubtedly that of the Univac B–O or Flow-Matic system developed in the mid-1950's.[5.21] More recent examples include General Electric's GECOS III (*G*eneral *C*omprehensive *O*perating *S*upervisor III)[5.22] and Integrated Data Store concepts; [5.23] the TDMS (*T*ime-Shared *D*ata *M*anagement *S*ystem) at System Development Corporation [5.24] and GIS (*G*eneralized *I*nformation *S*ystem) of IBM.[5.25] Heiner and Leishman (1966) describe a generalized program for record selection and tabulation allowing variable parameters for sort requirements, selection criteria, and output formats.[5.26]

In 1965, comparative operation of file management was demonstrated by different systems including COLINGO (Mitre Corporation), Mark III (Informatics, Inc.), BEST (National Cash Register), Integrated Data Store (G.E.), and an on-line management system of Bolt, Beranek, and Newman, Inc.[5.27] It was concluded that: "All of these systems were able to accomplish the processing required, but their approaches varied considerably, particularly in the file structures chosen for the application, executive control procedures, and level of language used in specifying the processing to be performed." (Climenson, 1966, p. 125).

In addition, we may note the examples of a file organization executive system,[5.28] a program management system involving a two-level file,[5.29] and a file organization scheme developed for handling various types of chemical information.[5.30] Another documentation application involving a list-ordered file is provided by Fossum and Kaskey (1966) with respect to word and indexing term associations for DDC (Defense Documentation Center) documents.[5.31]

In the area of common-purpose languages, also, there is need to reconcile the differing requirements with respect to different classes of data structures,[5.32] from those of numerical analysis processing through those of alphanumeric file management to those of list and multi-list processing.[5.33] List structures have been noted in several of the file management systems mentioned and it is to be noted further that: "Linked indexes and self-defining entries are an extension of list processing techniques." (Bonn, 1966, p. 1869). For non-numeric data processing applications, in general, symbol string manipulation, list processing and related programming techniques have been of particular concern.[5.34]

While many advantages of list-processing techniques have been noted, a number of disadvantages are also reported. Among the major advantages are the recursive nature of list processing languages [5.35] and adaptability to dynamic memory allocation and reallocation.[5.36] Also, languages of this type are "well suited to symbol manipulation, which means that it is possible to talk about the *names* of variables, and perform computations which produce them" (Teitelman, 1966, p. 29), and "by means of list structures . . . a three-dimensional spatial network can be modeled in computer memory." (Strom, 1965, p. 112).

Typical disadvantages to be noted include lack of standardization,[5.37] degree of programming sophistication required,[5.38] and wastage of storage space.[5.39] Major difficulties are often encountered in updating and item deletion operations [5.40] and in dealing with complex data structures.[5.41]

We may ask also to what extent the available list-processing and symbol manipulation programming languages are adequate for current application needs? [5.42] To what extent are they useful for the investigation of further needs? In particular, it is noted that "unfortunately, while these languages seem in many ways directly tailored to the information retrieval work, they are also in other respects very awkward to use in practice." (Salton, 1966, p. 207).

List-processing languages and structures are particularly clumsy, moreover, for multiply interrelated and cross-associated data.[5.43] Short of truly large-scale associative memories, effective compromises are needed as between list structures, including multilist programming languages, and file organizations that will provide economy of both storage and access.[5.44]

Beyond list processing procedures there are trees, directed graphs, rings, and other more complex associative schemes.[5.45] A relatively early example is that of "Rover" with "up links" and "side links" as well as "down links".[5.46] Savitt et al., 1967, describe a language, ASP (*A*ssociation-*S*toring *P*rocessor), that has been designed to simplify the programming of nonnumeric problems, together with machine organizations capable of high-speed parallel processing.[5.47]

Ring structure language systems are represented by Sketchpad developments [5.48] and the work of Roberts at M.I.T. for graphical data processing [5.49] and by systems for use in question-answering and similar systems, such as Project DEACON.[5.50] Still other associative structure developments are discussed for example, by Ash and Sibley (1968),[5.51] Climenson (1966),[5.52] Craig et al., (1966),[5.53] Dodd (1966),[5.54] and Pankhurst (1968).[5.55]

There are certainly those who need far more generalized multipurpose languages and, with equivalent force, those who advocate specialized, man-oriented, and special-purpose languages. A specific current design problem has to do with an appropriate compromise between these apparently contradictory comments. A future R & D requirement is to seek more effective solutions. Thus Licklider insists upon the need to bring on-line "conversational" languages more nearly abreast with the more conventional programming languages as an R & D challenge.[5.56]

5.1.3. Problem-Oriented and Multiple-Access Language Requirements

Increasing needs for advanced special-purpose program language developments have been recognized for the areas of man-machine interactive problem-solving and computer-aided instruction applications, graphical manipulation operations, and simulation applications, among others. It is noted in particular that "their power [that of problem-oriented languages] in the extension of computing lies in the fact that the expert knowlledge of skilled analysts in particular fields can be incorporated into the programs, together with a language which is native to the field, or nearly so, and can thereby break down the barriers of economics, of lack of familiarity with the computer, and of time." (Harder, 1968, p. 235).

Important requirements in programming languages reflect, predictably, those of multiple-access and time-shared systems involving a suitable hierarchy of languages so that the relatively unsophisticated user may converse freely with the machine without interference to other users or to the control and monitor programs and yet also draw upon common-use programs and data. The effective use of such systems in turn demands extremely tight and sophisticated programming to keep "overhead" to a minimum [5.57] and to provide dynamic program and data location and relocation. Relatively recent developments in this area are discussed by Bauer, Davis, Dennis and Van Horn, Licklider, Clippinger, Opler, and Scherr among others.[5.58] Bauer (1965, p. 23) suggests in particular that: "Entirely new languages are needed to allow flexible and powerful use of the computer from remote stations."

Multiple-access systems and networks obviously require R & D efforts in the development of language systems "optimized for remote-on-line use" (Huskey, 1965, p. 142). Opler points out, first, that "for the most difficult areas—telecommunication, process control, monitors, etc.—real-time languages have provided little assistance," and, secondly, that "the task of developing a complete new real-time language would be interesting and challenging since it would require reconsideration of the conventional procedure and data defining statements from the *viewpoint* of the real-time requirements." (Opler, 1966, p. 197).

Further, on-line problem-solving applications require dynamic and flexible programming capabilities.[5.59] Experimentation with the working program should be permitted with due regard for system protection and control.[5.60] Generalized problem-solving capabilities should be available in the language system without necessary regard to specific applications.[5.61] Such programs should be extensively self-organizing, self-modifying, and capable of adaptation or tentative "learning."[5.62]

Then it is to be noted that languages for on-line use should be relatively immune to inadvertent user errors.[5.63] Teitelman comments, for example, that "in languages of this type, FORTRAN, COMIT, MAD, etc., it is difficult to write programs that construct or modify procedures because the communication between procedures is so deeply embedded in the machine instruction coding, that it is very difficult to locate entrances, exits, essential variables, etc." (1966, p. 28).

In language systems such as TRAC,[5.64] the powerfulness is largely buried in specific machine processors for this language—the user is freed from learning a number of arbitrary exceptions, he is not able to "clobber" the underlying processor by inadvertent goofs, he is able iteratively to name and rename strings and procedures he wishes to use largely in terms of his own convenience, and he is able to make use of the language and system with minimal training or prior experience.

Related problems affect the design of special-purpose languages ("the design of special-purpose languages is advancing rapidly, but it has a long way to go," Licklider, 1965, p. 66), the interaction of executive and console languages ("wherever remote consoles are used, we find the users enthusiastic. However, they always hasten to add that there is much to learn about the design of executives and processors for console languages," (Wagner and Granholm, 1965, p. 287), the provision of adequate debugging aids ("the creation of large programming systems using remote facilities requires a number of debugging aids which range in complexity from compilers to simple register contents request routines." Perlis, 1965, p. 229), and the development of effective modularity in programs and compilers ("it will be necessary for the software to be modular to the greatest extent possible because it will need to work up to the next level of software." Clippinger, 1965, p. 211).

In connection with the latter requirement Lock discusses the desirability of an incremental compiler which is characterized by its ability "to compile each statement independently, so that any local change in a statement calls only for the re-compilation of the statement, not the complete program." (1965, p. 462).

Time-sharing or time-slicing options and graphical communication possibilities cast new light not only upon the problem-oriented but also upon the user-oriented languages and improved possibilities for man-machine communication and interaction. Effective compromises between the system design, the programmer, and the client have not yet been met, even although the demands of modern systems are increasing in complexity.

The problems of effective programming and utilization reach back beyond specific routines, specific languages, and specific equipment. They are involved in all the many questions of systems planning, systems managment and systems design. For example, in time-shared operations, "considerably greater attention should be focused on questions of economy in deciding on the tradeoff between hardware and software, in using storage hierarchies, and in determining the kind of service which the time-sharing user should be offered." (Adams, 1965, p. 488). Finally, the critical problems reach farther back than the potentialities of hardware, software and systems planning combined, to fundamental question of why, how, and when we should look to machines for substantial aid to human decision-making and problem-solving processes.

"An analysis of the various requirements that a programming language must satisfy (to be *known* both by the job-originator and the job-executor and to be capable of expressing both what the first wants to be done and what the second is capable of doing) involves basic researches on the linguistic nature of programming languages." (Caracciolo di Forino, 1965, p. 224).

5.1.4. Heirarchies of Languages and Programming Theory

Direct machine-language encoding and programming was the first and obvious approach to both numeric and *non*-numeric data processing problems. In both areas, forms of communication with the machine that are more congenial to the human user have been developed, as formal "programming languages" (FORTRAN, ALGOL, COBOL, and the like).[5.65] In addition, special program languages to facilitate either problem-solving and question-answering systems, or textual data processing, or both; (such as list-processing techniques, IPL–V, LISP, COMIT, SNOBOL, more recently TRAC, and others)[5.66] have been developed. More and more, however, it is beginning to be recognized that *hierarchies* of language are essential to present and foreseeable progress.[5.67]

Burkhardt (1965, p. 3) lists a spectrum of programming languages on the basis of the "declarative freedom" available to the user, from absolute machine languages with none, to "declarative languages" which provide a description of the problem and freedom of both procedure and solution. Certainly, for the future, "the entire spectrum of language from binary machine code to the great natural languages will be involved in man's interaction with procognitive systems." (Licklider, 1965, p. 104).

In the area of desired hierarchies of languages, we note such corroborating opinions as those of Salton who asks for compiling systems capable of handling a variety of high-level languages, specifically including list processing and string manipulations[5.68] and of Licklider who points out that in each of many subfields of science and technology there are specific individual problems of terminology, sets of frequently used operations, data structures, and formulas, indicating a very real need for many different user-oriented languages.[5.69] However, in his 1966 review, the first ACM Turing Lecture, Perlis concludes: "Programmers should never be satisfied with languages which permit them to program everything, but to program nothing of interest easily. Our progress, then, is measured by the balance we achieve between efficiency and generality." (1967, p. 9).

Moreover, even in a single system, it may be necessary not only to reconcile but to combine the contradictory advantages and disadvantages of differing levels of programming language in various ways. Thus Salton states "it is possible to recognize five main process types which must be dealt with in an automatic information system: string manipulation and text processing methods, vector and matrix operations, abstract tree and list structure manipulations, arithmetic operations, and finally sorting and editing operations." (Salton, 1966, p. 205). A second complicating factor relates to the still unusually fluid situation with respect to hardware developments, logical design, and the increasing interdependence of hardware-software factors in the consideration of future system and network design possibilities.

Beyond the investigation, development, and experimental application of advanced programming languages for specific types of application such as graphical data processing, simulation, or on-line question-answering and problem-solving systems, study is needed of fundamental problems of programming theory.[5.70] For example Halpern notes ". . . the increasingly wide gulf between research and practice in the design of programming languages." (1967, p. 141), while Alt emphasizes that "we do not yet have a good theory of computer languages, and we are nowhere near the limit of the concepts which can be expressed in such languages." (1964, p. B.2–1).

There is also to be noted in the current state of the art in the computer and information sciences an increasing concern for the relationships between formal modelling techniques, generally, the questions of formal languages, and the development of powerful, general-purpose programming languages.[5.71] Karush emphasizes that "the development of an integrated language of mathematical and computer operations is part of a more general problem associated with the automation of control functions. This is the problem of formalism which embraces both mathematical representations of systems and representations of the processes of actual execution of systems, by computer or otherwise." (1963, p. 81).

A similar concern is expressed by Gelernter: "Just as manipulation of numbers in arithmetic is the fundamental mode of operation in contemporary computers, manipulation of symbols in formal systems is likely to be the fundamental operating mode of the more sophisticated problem solving computers of the future. It seems clear that while the problems of greatest concern to lay society will be, for the most part, not completely formalizable, they will have to be expressed in some sort of formal system before they can be dealt with by machine." (1960, p. 275).

High-order relational schemes both in languages and in memory structures will thus be required.[5.72] For example, "the incorporation in procedural programming languages of notations for describing data structures such as arrays, files, and trees, and the provision to use these structures recursively together with indications of the scope of definition, will help greatly with the storage allocation problem and assist the programmer organizationally . . ." (Barton, 1963, p. 176). In this connection, Press and Rogers (1967) have described the IDEA (*I*nductive *D*ata *E*xploration and *A*nalysis) program package for the detection of inherent structure in multivariate data.[5.73]

We note also that "even in the more regular domain of formal and programming languages, many unsolved practical and theoretical problems remain. For example, the matter of recovery from error in the course of compilation remains in a quasi-mystical experimental state, although some early results, applicable only to the simplest of languages suggest that further formal study of this problem could be worth while." (Oettinger, 1965, p. 16).

Requirements for continuing research and development activities in the area of computing and programming theory are increasingly seen as directly related to needs for more effective multi-access time-sharing, multi-programmed, and multiprocessor systems. It can be foreseen that "*Organizational generality* is an attribute of underrated importance. The correct functioning of on-line systems imposes requirements that have been met *ad hoc* by current designs. Future system designs must acknowledge the basic nature of the problems and provide general approaches to their resolution." (Dennis and Glaser, 1965, p. 5).

What are some of the difficulties that can be foreseen with respect to the further development of hierarchies of systems? Scarrott suggests that "the problems of designing and using multilevel storage systems are in a real sense central to the design of computing systems" (1965, p. 137), and Burkhardt warns: "As long as actual computers are not well understood there will not be much hope for very successful development of useful universal processors." (1965, p. 12).

5.2. Processor and Storage System Design Considerations

In the area of information processing systems themselves, current trends have been marked not only by new extensions to the repertoires of system configurations available for the large, high-cost, high-speed processors but also by a continuing tendency to the development of computer system "families." Increasing attention is being given to both "upward" and "downward" compatibility—that is, to means by which programs operable on a large system may also operate on a smaller, slower, or less expensive member of the same family, and vice versa.

Increasing attention has also been given to providing adjuncts to existing and proposed systems which will give them better adapatability to time-sharing and on-line multiple-access requirements. Similarly, the requirements for handling a variety of input sensing modalities and for processing more than one input channel in an effectually simultaneous operation clearly indicate needs for continuing research and development efforts in the design and use of parallel processing techniques, multiprocessor networks, time-shared multiple access scheduling and multiprogramming.

Hierarchies of languages are implied as we have seen, ranging from those in which the remote console user speaks to the machine system in a relatively natural language (constrained to a greater or lesser degree) to those required for the highly sophisticated executive control, scheduling, file protection, accounting, monitoring, and monitoring instrumentation programs.

Tie-in to various communication links, generally, should include remote consoles, closed circuit TV, facsimile, voice quality circuits, and the like, with capability for real-time processing. Message security protection facilities are often required, including encoding and decoding. Access to error detection and error correction mechanisms are also necessary.

Overall system design requirements indicate also the necessary exploitation of new hardware technologies, new storage media, associative-memory procedures for file and data bank organization and management, the use of dynamic reallocations of space and access to both programs and files or data banks in multiple-access systems, protective and fail-safe measures, and the development of hierarchies of languages of access and usage, hierarchies of stored data files, and hierarchies of systems.[5.74]

Many of the above factors are discussed in other sections of this report or in other reports in this series. Here, we will consider briefly some of the problems of central processor design, parallel processing, and hardware-software interdependence.

5.2.1. Central Processor Design

With regard to the central processing system, it is noted that it should be operable in both time-sharing and batch processing modes, and that it provide simultaneous access to many users. Efficient multiple access should be provided to the hierarchies of storage with the user having, in effect, virtually unlimited memory.[5.75] There should be a capability for accessing either internal or auxiliary associative memory devices.

A continuing problem in processor-storage system design is that of address-circuitry.[5.76] Closely related to this problem are questions of content-identification-matching whether for sequential or parallel access. Indirect addressing and multiple relative addressing via a number of index registers is an important consideration.[5.77]

Moreover, direct program access to all registers by ordinary instructions and with interlock protection features is often required. If the index registers can be simultaneously and interchangeably used as instruction counters, there are additional parallel processing benefits. For example, such capabilities can provide for jumping to the *n*th instruction from the present one, determining whether an instruction has been executed or not, and other flexible capabilities for debugging, diagnostic, and evaluation purposes. It should be possible to manipulate index registers several at a time.

System users may need a relatively long word length to provide numerical accuracy in long floating point values, for manipulation of large matrices, to provide duplex operations on two sections of the word simultaneously as in complex number processing, and the like. Automatic unpacking of word subsets in variable sized bytes is also recommended for future processor design. Salton indicates needs for "flexible instructions operating on individual bits and characters, and flexible branching orders. Pushdown store instructions, such as 'pop' or 'push' should also be useful for the list operations." (1966, p. 209).

Also desirable is the ability to access a word simultaneously from more than one computer system or component with automatic protection interlocks in case of conflicts. Power-failure protection systems should be available and protection should also be provided against unauthorized access to various memory and data bank sections.

More flexible pagination [5.78] is needed for some important applications. For example, in graphic data processing, dynamic memory reallocation procedures requiring fixed pagination would be awkward to use and highly inefficient. Storage allocation should be under programmer control. For example, if pictorial data overflows the boundaries of a page, at least 4 and as many as 9 pages may be required since such data must be processed as a two-dimensional array. The system designer needs to avoid as far as possible the problems of unnecessary and clumsy programming in order to apply a single procedure to such arrays. For example, Wunderlich points out in connection with sieving procedures for computer generation of sets and sequences that "there are obvious programming difficulties connected with sieving on a field of bits." (1967, p. 13).

Another hardware-software desideratum here is obviously the need for efficient bit-manipulation capabilities. For example, the user would like to find, for a given gray-level representation of a graphic input that, at a given location and blackness level, some or all or none of the neighboring locations have the same blackness level recordings (this is important in eliminating "fly specks" from further processing, in filling-in "holes" that result from imperfect printing impressions, and also in determination of the relative locations of centers of blackness when attempting to reconstruct three-dimensional imaging for serial sequences of two-dimensional image representations).

Problems of computer design as well as programming for *array* processing are discussed by Senzig and Smith (1965) in terms of a worldwide weather prediction system and by Roos (1965) in terms of the ICES (*I*ntegrated *C*ivil *E*ngineering *S*ystem) at M.I.T.[5.79] Association matrices present a special form of data arrays requiring efficient manipulation and processing. Such considerations are particularly important in the experimental research or on-line instrumentation situations.[5.80] In addition, bit-manipulation and array-processing requirements are severely constrained in commercially available systems.

A requirement of major future importance (especially for chemical information searching, file, organization, mapping functions and graphic data processing) is for efficient bit manipulation capabilities, including convenient Boolean processing and transplant features. Again, bit manipulation capabilities are important because many operations require consideration of all the orthogonal neighbors of a single bit position.

In future system designs, increasing needs for multivalued logic approaches can also be foreseen. In general, a binary (two-valued) logic pervades information processing system design and the basic methods of information representation as of today. For the future, however, attention needs to be directed toward multivalued logic systems and to direct realizations of the *n*-ary relations between the data elements of stored information. There are new technological possibilities that point in this direction (e.g., new devices that are capable of at least ternary response,[5.81] or multiple response by color-coding techniques from a single "bit" recording on advanced storage media). In addition, parallel processing, associative processing, and iterative circuit techniques point the way to new complexities of program command and control and to new, multi-valued, processing opportunties as well.

Then, as Wooster comments: "Radically different types of computers may well be needed. At present, the best way of building these seems to be through the creation of logical structures tending more and more in the direction of distributed logic nets, wherein vast numbers of processes occur simultaneously in various parts of the structure. Right now, the best building blocks for such systems seem to be multifunctional microprogramable logic elements." (1961, p. 21).

Increasing *complexity* of central processor design is indicated by developments in advanced hardware technologies;[5.82] while increasing *flexibility* is dictated by dynamic reconfiguration requirements.[5.83] Modularity is an important consideration.[5.84] The critically challenging, interacting problems of both design, programming and utilization of multiprocessors and of parallel processing are emphasized by Brooks (1965), Amdahl (1965), Burkhardt (1965), and Opler (1965), among others. Thus: "The use of multicomputers implies intercommunication, with the associated implications of interconnection, reconfiguration and interlocking." (Amdahl, 1965, p. 38).

5.2.2. Parallel Processing and Multiprocessors

The possibilities for the use of parallel processing techniques should receive increased R & D attention. Such techniques may be used to carry out data transfers asynchronously with respect to the processing operations,[5.85] to provide analyses necessary to convert sequential processing programs into parallel-path programs,[5.86] or to make allocations of system resources more efficiently because constraints on the sequence in which processing operations are executed can be relaxed.[5.87] Applications to the area of pattern recognition and classification research and to other array processing operations are obvious.[5.88]

However, there are problems of effective use of parallel processing capabilities. Some examples of the discernible difficulties with respect to current parallel-processing research and development efforts have been noted in the literature as follows:

(1) "Multiprogrammed processors will require more explicit parallel control statements in languages than now occur." (Perlis, 1965, p. 189.)
(2) "Much additional effort will have to be put into optimizing compilers for the parallel processors that may dominate the computer scene of the future." (Fernbach, 1965, p. 84).
(3) "Computers with parallel processing capabilities are seldom used to full advantage." (Opler, 1965, p. 306).

There are also problems of R & D concern in programming language developments involved with increased use of parallel processing capabilities. The possibilities of "Do Together" provisions in compilers, first raised by Mme. Poyen in 1959,[5.89] add a new dimension of complexity for analysis, construction, and interpretation. Fernbach comments on the sparcity of attempts made to date on the potentials of parallel processing in programs for many problems. He states further that while the tasks of segmenting the problem itself for parallel processing attack are formidable, "they must be undertaken to establish whether the future development lies in the area of parallel processing or not."[5.90] Then there is need for judicious intermixtures of parallel and sequential processing techniques in specific design, programming, or application situations.[5.91]

Parallel processing potentials are also closely related to, and may be interwoven with, *multiprocessing* systems which involve: "The simultaneous operation of two or more independent computers executing more-or-less independent programs, with access to each other's internal memories . . ." (Riley, 1965, p. 74). In particular, the Solomon Computer and Holland Machine concepts may be noted.[5.92] For another example, increasing parallelism of operation of a multiple access processing system has been investigated at the Argonne National Laboratory in terms of an "Intrinsic Multiprocessing" technique consisting of *n* time-phased "virtual" machines which time-share very high speed execution hardware (Aschenbrenner et al., 1967), while ILLIAC III has been designed for parallel processing of pictorial data.[5.93]

5.2.3. Hardware-Software Interdependence

The earlier dichotomy as between "hardware" and "software" considerations is beginning to yield, not only to the increasing interdependence of the two factors in many information processing application requirements, but also to technological developments in "firmware" (in effect, wired-in microprogramming[5.94]) and to growing recognition of the critical importance of more precise and comprehensive "brainware" in systems planning, design, specification, and implementation.[5.95]

Is it currently possible to separate computer and storage system design considerations from those of programming language design and of programmed executive control? Several experts testify that, if it is still possible today, it will soon be so no longer.[5.96] It can be quite clearly seen that the areas of computer theory and program design are becoming increasingly interdependent with those of adequate programming languages, "software", and user-tolerance levels. At the same time, new possibilities for multicommunicator, multiprocessor, and multi-user networks are increasingly coming to the fore.

The growing interdependence is stressed, for example, by Schultz (1967),[5.97] and by Lock (1965) who notes the strongly increasing influence of multiprogrammed, on-line systems upon the organization of the storage facilities. Scarrott (1965, p. 137) for another example, insists that "the problems of designing and using multilevel storage systems are in a real sense central to the design of computing systems."

Thus, "as we enter an era of bigger and more complex systems some new requirements are coming to be of major importance.

- Will we be able to minimize the program handling by proper allocation to primary, e.g., core, or secondary, e.g., drum or disk, storage?
- Will we be able to incorporate changes to the functional operation of the system?
- Will we be able to modify the system to accommodate new or additional hardware?
- Will we be able to add a completely new function to an already operating system?" (Perry, 1965, p. 243).

In the next section, therefore, we will consider some of the advanced hardware developments before discussing such overall system design considerations as debugging, on-line instrumentation and diagnosis, and simulation.

6. Advanced Hardware Developments

Certain obvious overall system design requirements have to do with the further extensive development and application of advanced hardware technologies, especially opto-electronics generally (and lasers and holography in particular), with integrated circuit techniques, and with improved high-density storage media.

Recurrent themes in current progress toward very-high-speed, computer-controlled access to primary, secondary and auxiliary storage banks, from the standpoint of hardware technology, include the questions of matching rates of data-and/or-instruction access to those of internal processing cycles, and of the prospects for integrated circuit and batch fabrication advantages in design and construction.

These new technologies may also be combined in various ways. For example, Lockheed Electronics has been using deflected laser beams to scan photochromic planes very rapidly and very accurately,[6.1] laser and holographic techniques are conjoined in equipment designed to photograph fog phenomena in three dimensions,[6.2] and it has been reported that "laser devices show promise of very fast switching which together with optical interconnections could provide digital circuits that are faster than electronic circuits." (Reimann, 1965, p. 247).

6.1. Lasers, Photochromics, Holography, and Other Optoelectronic Techniques

New hardware developments that are technically promising in terms of the long range research and development necessary to support future improvements in information processing and handling systems include the development of special laser techniques for switching, storage, and other purposes, and the possible use of holograms or kinoforms for 3-dimensional pattern recognition and storage.

6.1.1. Laser Technology

Writing in 1965, Baker and Rugari have pointed out that "a wide variety of lasers have been discovered and developed since the first laser device was operated five years ago.[6.3] Lasers can be classed into three basic types: solid-state, semiconductor, and gaseous. Typical examples are the ruby solid-state laser, gallium arsenide semiconductor laser, and the neon-helium gas laser." (1966, p. 38).

Certainly, lasers, whether of the gas, fluorescent crystal, or semiconductor type,[6.4] are finding many new possibilities of application in computer, communication, and information processing systems.[6.5] As sources of illumination they can provide greater display efficiency[6.6] and greater resolution with respect to display systems involving lightbeam deflection techniques (Soref and McMahon, 1965, p. 60),[6.7] and they provide an effective aid to the boundary and contrast enhancement techniques for image processing developed at the National Physical Laboratory at Teddington, England. More specifically, this technology promises new developments in space communications,[6.8] in memory construction and design,[6.9] in the development of analytical techniques such as Raman spectroscopy and photomicroscopy,[6.10] in the identification of fingerprints,[6.11] in quantization of high resolution photographs[6.12] and in the use of holograms for collection, storage, and regeneration of two- and three-dimensional data.[6.13]

Small, very high-speed memories may be driven by laser beams,[6.14] and laser components contribute to the design of "all-optical" computers[6.15] and computer circuits and components.[6.16] Laser inscribing techniques are being investigated for such applications as large screen real-time displays,[6.17] and for highly compressed data recording, for example, at Precision Instrument Company.[6.18] As of March 1969, it could be reported that orders had been placed for UNICON systems by Pan American Petroleum Corporation, and were under consideration by several other organizations, including U.S. Government agencies.[6.19] In particular, the National Archives and Records Service has been studying the possibilities of converting present magnetic tape storage to this system.[6.20]

Investigations of future technical feasibility of using laser devices for high speed data storage and/or processing have thus been complemented by exploration of possibilities for recording onto very large capacity storage media as also in developments at Honeywell,[6.21] at the Itek Corporation,[6.22] and at RCA,[6.23] an IBM system designed for and now in operation at the Army Electronics Command as well as IBM developments in variable frequency lasers,[6.24] and a recording system from Kodak that uses fine-grained photographic media, diffraction grating patterns, and laser light sources.[6.25] Holographic techniques may also be applied to the development of associative memories with possible analogies to human memory-recall systems.[6.26]

Kump and Chang (1966) describe a thermostrictive recording mechanism effected on uniaxial Permalloy films by the application of a local stress induced by either a laser or an electron beam, promising large capacity memories of better than 10^6 bits per square inch storage efficiency.[6.27] Then there are combined optical and film techniques for digital as well as image or analog recording and storage. Specific examples include IBM photo-chip developments,[6.28] thermal recording developments at the NCR research laboratories,[6.29] Precision Instrument's UNICON System,[6.30] and, in general, the area of photochromic storage technology.

Areas of continuing R & D concern with respect to laser communications possibilities include questions of modulation and transmission,[6.31] acquisition and tracking problems,[6.32] isolation from atmospheric interferrence conditions,[6.33] and possibilities for controlled atmosphere systems.[6.34]

Vollmer (1967) notes that an experimental short-range laser communication system has narrow beam width with significant advantages for privacy. In particular, "operation at 9020 Å enhances this privacy by virtue of its invisibility." (p. 67.) Some examples of the experimental use of lasers for communications purposes were given in an earlier report in this series,[6.35] and it was noted that the most successful ventures to date have been at opposite ends of the distance spectrum.[6.36] However, laser scanning techniques combined with other means of communication may offer important gains in high-resolution facsimile transmission. For example, a system developed by CBS Laboratories uses a laser beam to scan photographic film, convert to video signals, and transmit, via satellite, military reconnaissance pictures from Viet Nam to Washington.[6.37]

Continuing requirements for further developments in the application of lasers in display systems involve, for example, efforts directed toward less expensive high quality semiconductor lasers [6.38] and toward solving problems of deflection, modulation, and focusing.[6.39] Kesselman suggests that results to date in terms of laser displays are inconclusive and that practical applications are not likely in the near future (1967, p. 167). As in the case of laser versus electron beam display,[6.40] the absence of requirements for vacuum techniques favors the eventual use of laser rather than electron beam techniques in many high density data storage recording applications.[6.41]

6.1.2. Photochromic Media and Techniques

By definition, photochromic (or phototropic) compounds exhibit reversible effects or color changes, resulting from exposure to radiant energy in the visible or near visible portions of the spectrum.[6.42] Such media give excellent resolution and reduction characteristics, and because of the reversibility property, they can theoretically be erased and rewritten repeatedly,[6.43] although a continuing area of R & D concern is that of problems of fatigue.[6.44] They also enable storage of images with a wide range of gray scale.[6.45] Such materials have been known for at least a hundred years or more (Smith, 1966). In fact, as Smith suggests, they may have provided the means for achieving the world's first "wrist-watch." [6.46]

Tauber and Myers (1962) and Hanlon et al. (1965) offer summaries of NCR efforts to provide commercial applicability to photochromic recording techniques for large-capacity micro-image storage files.[6.47] A British example of application is the Technical Information on Microfilm Service.[6.48]

A less favorable characteristic of the photochromic material appears in the case of storage files—the permanency of recording depends on ambient temperature, ranging from only a few hours at normal room temperatures to perhaps several years under rigid temperature controls.[6.49] Therefore, for mass and archival storage, the NCR system involves transfer from the photochromic images to a high-resolution photographic emulsion for permanent files.[6.50] The remaining advantages are two-fold. First, the reduction is impressive: 1,400 pages of the text of the Bible on an approximately 2″ x 2″ film chip is the widely demonstrated example (Fig. 2). Secondly, 'spot' erasure and rewriting provides an important inspection and error correction capability. It is claimed that: "Instantaneous imagery followed by immediate inspection permits the production of essentially 'errorless' masters for the first time". (Hanlon et al., 1965, p. 10).

In the area of internal memory and switching design, Reich and Dorion (1965) report of the photochromic techniques that: "The photochromic medium has extremely large storage capacity latently available in physically small dimensions. The basic photochromic switches are the molecules themselves . . . Photochromic media can be employed for many write-erase-rewrite cycles and give almost nondestructive read . . . Appropriate photochromic systems can retain stored data without power consumption . . . The memory can probably be designed to be stored for quite a long time." (p. 572) [6.51]

A photochromic medium in the form of transparent silicate glass containing silver halide particles has been suggested for such applications as erasable memories, displays for air traffic control operations, and optical transmission systems.[6.52]

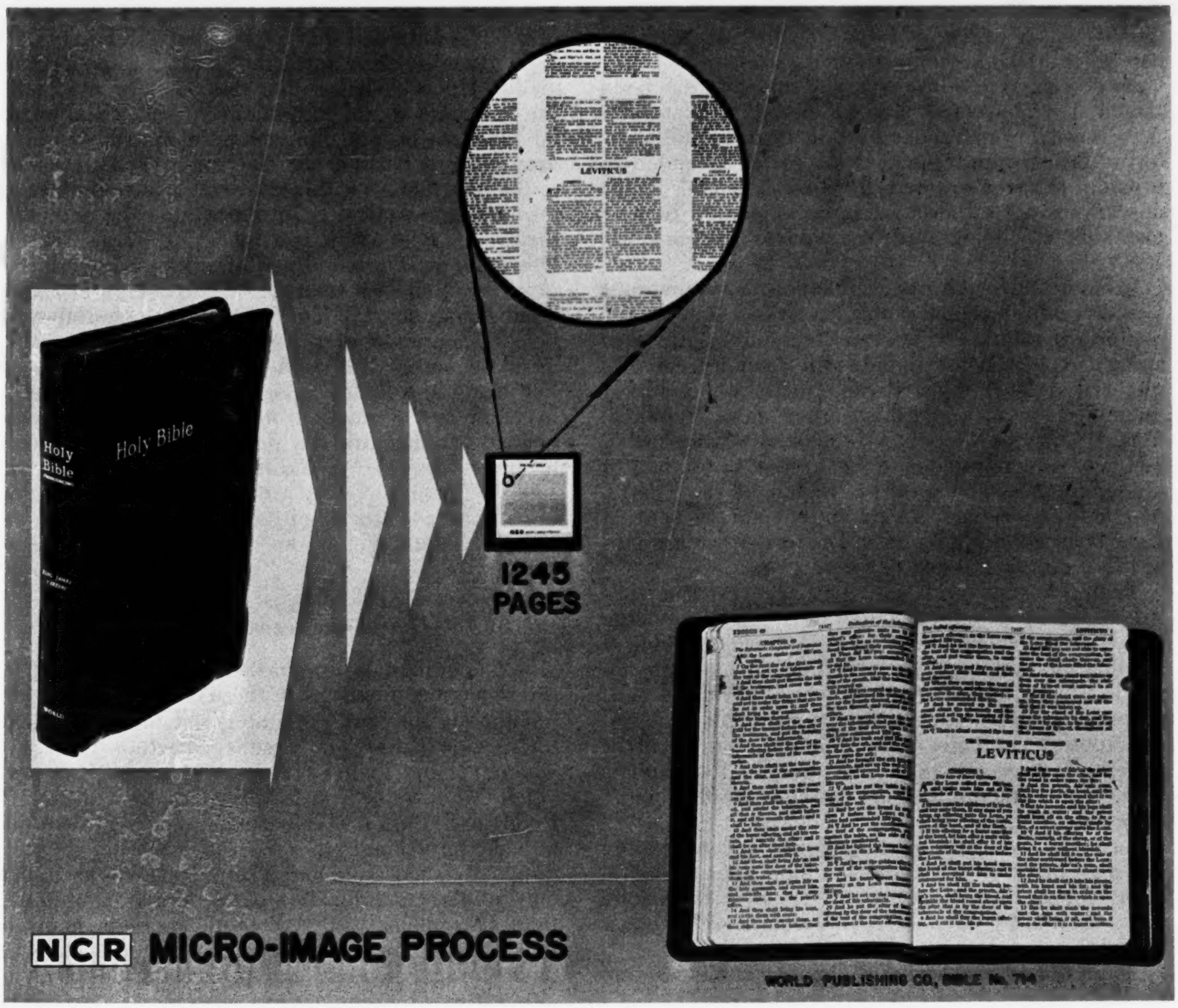

FIGURE 2. *Photochromic data reduction.*

In addition, it is to be noted that photochromic films may be activated by CRT phosphors for use in information display systems (Dorion et al., 1966)[6.53] and may also be used for real-time target tracking.[6.54] Recent developments suggest the use of photochromics for *digital* data storage.[6.55]

Finally, the properties of photochromic materials might be used for improved performance of holographic recording, reconstruction and display systems.[6.56] Thus, "the use of self-developing photochromic devices in the place of the photographic plate would enhance the value of wavefront reconstruction microscope by permitting nearly real-time operation and eliminating the chemical development process." (Leith et al., 1965, p. 156).

6.1.3. Holographic Techniques

Holography is a new information processing technique, but it is, in fact, highly illustrative of needs for truly long-range R & D planning in many areas of computer and information sciences and technology, since it is by no means a *recent* area of investigation, the principles having been announced by Gabor as early as 1948.[6.57] The basic holographic phenomena are described by Cutrona (1965, p. 89) as follows: "A hologram is produced by recording on photographic film the interference pattern resulting from the illumination of some object with a wavefront from the same source".[6.58]

Leith et al. (1965, p. 151) point out further that "by combining conventional wavefront reconstruction techniques with interferometry, it has been possible to produce holograms from which high-quality reconstructions can be obtained. These reconstructions bear close likeness to the original object, complete with three-dimensional characteristics . . . The object can be a transparency, or it can be a solid, three-dimensional object".[6.59]

Armstrong (1965) emphasizes that, in general, no lenses are required and the reconstructed image can be magnified or demagnified as desired.[6.60]

As of early 1969, however, the question has been raised that holograms may be already outdated.[6.61] A new wavefront reconstruction device—the kinoform—is a computer-generated device intended to provide a reconstructed three-dimensional image of various objects with greater efficiency than is available with holographic procedures (Lesem et al., 1969).[6.62]

In addition to the use of holographic techniques for three-dimensional image storage and recall (including rotation[6.63]), these techniques are also being explored for bandwidth compression in pictorial data storage[6.64] the production of highly magnified images,[6.65] and other novel applications.[6.66] In particular, it has been claimed that holographic techniques offer a new potential for high-quality-image capture in regions of the electromagnetic spectrum extending beyond those that have been achieved by optical recording techniques in the the region of visible light.[6.67]

Then it has been reported that "General Electric's Advanced Development Laboratories, Schenectady, build a laser holograph reader—a device capable of reading characters in several ways. It can detect a single object out of many *without* scanning, or if scanning is used, can recognize up to 100 different characters. The holographic reader is said to show wide tolerance for variations in type font and is expected to find applications in the computer field." (Veaner, 1966, p. 208.)

Laser and holographic techniques in combination are also being investigated for high density digital data storage, for example, at the Bell Telephone Laboratories,[6.68] at Carson Laboratories,[6.69] and at IBM.[6.70]

Some special areas where advanced optoelectronic techniques and improved materials or storage media continue to be needed include "certain operations, such as two-dimensional spatial filtering (that) can be readily accomplished, in principle, with coherent light optics. Problems under consideration include: the effect of film-grain noise on the performance of a coherent optical system; the relation of film thickness and exposure; techniques for the making of spatial filters; and the effect on the reconstructed picture of various operations (such as sampling, quantization, noise addition) upon the hologram." (Quarterly Progress Report No. 80, Research Laboratory for Electronics, M.I.T., 221 (1966).)

McCamy (1967) reports recent extension of previous R & D investigations into fading and aging blemishes in conventional microforms to the effect of formation of such blemishes on information stored by means of holograms. It is to be noted further that certain types of holograms have an important immunity to dust and scratches.[6.71]

Possibilities for a holographic read-only store are under investigation at IBM (Gamblin, 1968), RCA (Viklomerson et al., 1968), and at the U.S. Army Electronics Command, Fort Monmouth. In particular, "it is intended that a hologram of a binary data array would constitute the card-like removable media. Upon insertion into the memory read unit, the hologram would continuously focus a real image on the data onto a photodetector matrix. Such an arrangement can permit electronic random access to the information within the array while eliminating the stringent optical requirements on the detectors involved." (Chapman and Fisher, 1967, p. 372).[6.72] Other R & D possibilities of interest include experimentation with acoustic[6.73] and computer-generated holograms.[6.74] The computer generation of holographic or kinoform recordings is thus another development in this area of advanced technology. For example, digital holograms may be generated by computer simulation of wave fronts that would emanate from particular optical elements arranged in specific geometrical relationships (Hirsch et al., 1968).[6.75] An interesting area of investigation is that of computer synthesis of holograms of three-dimensional objects which do not, in fact, physically exist.[6.76]

6.1.4. Other Optoelectronic Considerations

In general, it is emphasized that increasing interest has been evident in the use of optoelectronic techniques for both computer and memory design for a wide variety of reasons. Scarrott (1965) and Chapman and Fisher (1967) point to the high densities achievable with photographic media.[6.77] Reich and Dorion (1965) suggests a photochromic film memory plane, 2″ x 2″, with 645 subarrays individually accessible and a total capacity, assuming only 50 percent utilization of the film area, of better than 12 million bits.[6.78] Potentially, then, many of these techniques promise significant advances in data storage, in logic and processing circuitry, in alternative communications means, in computing or access speed, and in data collection with respect to two- and three-dimensional object representation, including spatial filtering.[6.79]

Bonin and Baird (1965, p. 100) list other applications of optoelectronic techniques for tape and card readers, position indicators, and recognition equipment. In addition, important new areas will include use in communication and transmission systems. Here it is noted that optical techniques as applied to advanced communication systems planning relate also to continuing theoretical investigations. Thus, "preliminary studies of communication systems employing optical frequencies have indicated three topics to which the concepts and techniques of modern communication theory may most profitably by addressed. They are (i) the import of quantum electrodynamics for the characteristics of efficient communication systems, (ii) the relevant description of device noise as it affects the performance of communication systems, and (iii) the statistical characterization of the atmosphere as a propagation channel at optical frequencies." (Quarterly Progress

Report No. 80, Research Laboratory for Electronics, M.I.T. 178 (1966).)

For use as computer logical elements, somewhat less attention has been paid to date to the optoelectronic techniques. However, Ring et al. (1965, p. 33) point out that "it well may be that optical devices which do not appear at all suitable as binary computer elements may be very effective computing devices in the context of some other logic structure (e.g., majority logic, multivalued logics)."

Reimann adds: "With the advent of the laser, efficient light-emitting diodes, and high-speed photodetectors, interest in the application of higher speed opto-electronic circuits to digital logic has increased. . . . We may in the future expect to see opto-electronic circuits which will combine laser amplifiers with other high-speed semiconductor devices." (1965, p. 248).

Then we note that optoelectronic techniques may also be used to attack some of the problems that increasingly plague the circuit designer.[6.80] Possibilities for circumventing interconnection limitations which become more severe as physical area per component is reduced are also stressed by Reimann (1965, p. 247). He states: "The possibility of signal connection between parts of the system without electrical or actual physical contacts are very attractive for integrated circuit techniques. With optical signals, a totally new approach to the interconnection of digital devices is possible."

Optoelectronic techniques as applied to the problems of large, inexpensive memories are not only promising as such,[6.81] they also may be used to attack the noise problems still posed by integrated circuits.[6.82] Thus Merryman savs "one attractive property of optoelectronic devices is their potential for isolation; they can get rid of the noise that is generated when two subsystems are coupled. The noise problem is even tougher in integrated circuit systems, because the transformers used in traditional methods of isolation are too bulky." (1965, p. 52).

6.2. Batch Fabrication and Integrated Circuits

In very recent years, it has been claimed that integrated circuitry is the most significant advance in computer hardware technology since the introduction of the transistor; [6.83] that it will bring important changes in the size, cost, reliability and speed of system design components,[6.84] and that advanced high-speed techniques paradoxically also indicate eventual lower costs.[6.85]

Many potential advantages of increased usage of LSI techniques are cited in the literature. These include, for example, applications in improved central processor unit speed or capacity performance, in system control and reliability, and in content-addressable (associative) memory construction and operation.[6.86] Wilkes suggests that parallelism achieved by use of these techniques may overcome present-day deficiencies of processing systems in such applications as pattern recognition.[6.87]

In terms of relatively recent R & D literature, Minnick (1967) provides a review of microcellular research, with emphasis upon techniques useful for batch-fabricated circuit design; Bilous et al. (1966) discuss IBM developments of large scale integration techniques to form monolithic circuit arrays, where on only nine chips it was possible to replicate a specific System/360 computer model, and, under RADC auspices, Savitt et al. (1967) have explored both language development and advanced machine organization concepts in terms of large scale integration (LSI) fabrication techniques.[6.88] That is, in general, where integrated circuits based on etched circuit board techniques had replaced discrete components, the LSI techniques of fabrication produce sheets of integrated logic components as units.[6.89]

To what extent do integrated fabrication techniques hold promise for future developments in very large yet inexpensive memories? Rajchman suggests that "the dominance of non-integrated memories is likely to be finally broken or at least seriously challenged by integrated memories, of which the laminated-ferrite-diode and the superconductive-thin-sheet-cryotron memories are promising examples." (Rajchman, 1965, p. 128.) And, further, that "it appears certain that energetic efforts will continue to be devoted towards integrated technologies for larger and less costly memories, as this is still the single most important hardware improvement possible in the computer art." (Rajchman, 1965, p. 128.) Other advocates include Gross,[6.90] Hudson,[6.91] Van Dam and Michener,[6.92] Pyke,[6.93] and Conway and Spandorfer.[6.94]

Hobbs says of silicon-on-sapphire circuits that their fabrication is suitable for large arrays and that they are indeed "promising, but presently being pursued by only one company." (1966, p. 38.) Of active thin-film circuits, he concludes: "Potentially cheaper and easier to fabricate very large arrays. Feasibility is not proven and utilization much further away." (Hobbs, 1966, p. 38.) The same reviewer continues: "Costs are expected to range between 3 and 5 cents per circuit in large interconnected circuit arrays . . . However, the ability to achieve these costs is dependent upon the use of large interconnected arrays of circuits and, hence, upon the computer industry's ability to develop logical design and machine organization techniques permitting and utilizing such arrays." (Hobbs, 1966, p. 39.)

Continuing R & D problems in terms of LSI technology include those of packaging design,[6.95] error detection and correction with respect to malfunctioning components; [6.96] the proper balance to be achieved between flexibility, redundancy, and maintenance or monitoring procedures, and questions of segmentation or differentiation of functional logic types.[6.97] One example of many special problems is reported by Kohn as follows: "In all batch fabricated memories, the problem of unrepairable element failures is predominant . . . It is an open question how complex and expensive the additional electronic circuits will be, which will disconnect the defective elements and connect the spare ones." (Kohn, 1965, p. 132.) On the other hand, special advantages of LSI techniques for self-diagnosis and self-repair have been claimed.[6.98]

6.3. Advanced Data Storage Developments

In the area of advanced hardware, the prospects for much larger, much faster, and more versatile storage systems must of course be a major R & D consideration. Current technological advances indicate the desirability of increasing use of integrated construction methods using ferrite aperture plates, thin films, laminated-diode combinations, field-effect transistors, and superconductive thin film systems, among other recent developments.[6.99] For another example, possible applications of echo resonance techniques for microwave pulse delay lines that would be suitable for high-speed memories are being explored at the Lockheed Palo Alto Research Laboratory. (Kaplan and Kooi, 1966).

Advanced hardware developments for improved data storage emphasize both higher speeds of access and readout and larger capacities at higher densities of storage. There are the small capacity, ultra-high-speed, memories of the read-only, scratchpad, and associative type. These typically supplement significantly larger capacity and slower speed "main memories". Next, there are continuing prospects for high density, very large capacity stores.

There is finally the question of R & D requirements in the area where the development of "artificial" memories are designed to replicate, so far as possible, known neurophysiological phenomena. For example, Borsellino and his colleagues at the University of Genoa are studying physical-chemical simulation, such as collagen "memories", in terms of possible mechanisms of axon action, connectivity of pulses, and currents through membranes. (Stevens, 1968, p. 31).

We may thus conclude with Licklider that "insofar as memory media are concerned, current research and development present many possibilities. The most immediate prospects advanced for primary memories are thin magnetic films, coated wires, and cryogenic films. For the next echelons, there are magnetic disks and photographic films and plates. Farther distant are thermoplastics and photosensitive crystals. Still farther away—almost wholly speculative—are protein molecules and other quasi-living structures." (Licklider, 1965, pp. 63–64).

6.3.1. Main Memories

Questions of advanced tehcnological developments related to data and program information storage and recall concern first of all the problems of "main memory"—that is, the preloaded, immediately accessible, information-recording space allocated at any one time to necessary system supervision and control, to user(s) programs and data, and to temporary work space requirements.

It is to be noted that "this 'main' memory size is related to the processing rate; the faster the arithmetic and logic units, the faster and larger the memory must be to keep the machine busy, or to enable it to solve problems without waiting for data." (Hoagland, 1965, p. 53).

Further, "this incompatibility between logic and memory speeds has led to increased parallel operation in processors and more complex instructions as an attempt to increase overall system capability." (Pyke, 1967, p. 161).

As of current technology, main memories are still usually magnetic core, with typical capacities of a million bits and cycle times of about one microsecond.[6.100] One relatively recent exception is the NCR Rod Memory Computer, which is claimed to have "about the fastest main memory cycle time of any commercial computer yet delivered—800 nanoseconds." (Data Processing Mag. **7**, No. 11, 12 (Nov. 1965).) This is a thin-film memory, constructed from beryllion-copper wires plated with magnetic coating.[6.101]

Petschauer lists the following trends which may be expected in magnetic memory developments in the near future:

"1. Trend toward simple cell structures—2 or 3 wire arrays.
"2. More automated assembly and conductor termination or batch-fabricated arrays.
"3. More fully automated plane testing.
"4. More standardization.
"5. Extended use of integrated or hybrid circuits.
"6. Improved methods of packaging for stack and stack interface circuits to reduce packaging and assembly costs.
"7. Reduced physical size." (Petschauer, 1967, p. 599).

With respect to current prospects for much larger, much faster main memories, Rajchman (1965) reviews possibilities for integrated construction methods using ferrite aperture plates, thin films, laminate-diode combinations, field-effect transistors, and superconductive thin film cryotrons.[6.102] It is noted further that "planar magnetic film memories offer many advantages for applications as main computer storage units in the capacity range of 200K to 5M bits." (Simkins, 1967, p. 593), and that "perhaps the most significant system advantage available to users of plated magnetic cylindrical thin film memory elements is a nondestructive readout capability. For main memory use, NDRO with equal Read-Write drive currents is most advantageous. It allows the greatest possible flexibility of organization and operation. For maximum economy, many memory words (or bytes) may be accessed by a single word drive line without need for more than one set of sense amplifiers and bit current drivers. The set contains only the number of amplifiers needed to process the bits of one word (or byte) in parallel." (Fedde, 1967, p. 595). Simpson (1968) discusses the thin film memory developed at Texas Instruments.[6.103]

Nevertheless, the known number of storage elements capable of matching ultrafast processing and control cycle times (100-nanosecond or less) are relatively few,[6.104] and there are many difficulties to be encountered in currently available advanced techniques.[6.105] Some specific R & D requirements indicated in the literature include materials research to lower the high voltages presently required for light-switching in optically addressed memories (Kohn, 1965),[6.106] attacks on noise problems in integrated circuit techniques (Merryman, 1965),[6.107] and the provision of built-in redundancy against element failures encountered in batch fabrication techniques (Kohn, 1965). In the case of cryotrons used for memory design, Rajchman (1965) notes that the "cost and relative inconvenience of the necessary cooling equipment is justified only for extremely large storage capacities" (p. 126), such as those extending beyond 10 million bits, and Van Dam and Michener (1967) concur.[6.108] Considerations of "break-even" economics with respect to cryogenic-element memories such as to balance high density storage and high speed access against the "cooling" costs has been assessed at a minimum random-access memory requirement of 10^7 bits.[6.109] As of 1967–68, however, practical realizations of such techniques have been largely limited to small-scale, special-purpose auxiliary and content-addressable memories, to be discussed next.

6.3.2. High-Speed, Special-Purpose, and Associative or Content-Addressable Memories

Small, high-speed, special-purpose memories have been used as adjuncts to main memories in computer design for some years.[6.110] One major purpose is to provide increased speed of instruction access or address translation, or both. The "read-only-stores" (ROS) in particular represent relatively recent advances in "firmware," or built-in microprogramming.[6.111]

It is noted that "the mode of implementing ROM's spans the art, from capacitor and resistor arrays and magnetic core ropes and snakes to selectively deposited magnetic film arrays." (Nisenoff, 1966, p. 1826.) An Israeli entry involves a two-level memory system with a microprogrammed "Read Only Store" having an access time of 400 nanoseconds. (Dreyer, 1968.) A variation for instruction-access processes is the MYRA (*MYR*i *A*perture) ferrite disk described by Briley (1965). This, when accessed, produces pulses in sequential trains on 64 or more wires. A macro instruction is addressed to an element in the MYRA memory which then produces gating signals for the arithmetic unit and signals for fetching both operands and the next macro instructions. Further, "Picoinstructions are stored at constant radii upon a MYRA disk, in the proper order to perform the desired task. The advantages of the MYRA element are that the pico-instructions are automatically accessed in sequence . . ."[6.112] Holographic ROM possibilities are also under consideration.[6.113]

In the area of associative, or content-addressable memories,[6.114] advanced hardware developments to date have largely been involved in processor design and provision of small-scale auxiliary or "scratch-pad" memories rather than for massive selection-retrieval and data bank management applications.[6.115] "Scratchpad" memories, also referred to as "slave" memories, e.g., by Wilkes (1965),[6.116] are defined by Gluck (1965) as "small uniform access memories with access and cycle times matched to the clock of the logic." They are used for such purposes as reducing instruction-access time, for micro-programming, for buffering of instructions or data that are transferable in small blocks (as in the "four-fetch" design of the B 8500),[6.117] for storage of intermediate results, as table lookup devices,[6.118] as index registers and, to a limited extent, for content addressing.[6.119]

Another example is the modified "interactive" cell assembly design of content-addressable memory where entries are to be retrieved by coincidence of a part of an input or query pattern with a part of stored reference patterns, including other variations on particular match operations (Gaines and Lee, 1965).[6.120] In addition, we note developments with respect to a solenoid array[6.121] and stacks of plastic card resistor arrays,[6.122] both usable for associative memory purposes; the GAP (*G*oodyear *A*ssociative *P*rocessor),[6.123] the APP (*A*ssociative *P*arallel *P*rocessor) described by Fuller and Bird (1965),[6.124] the ASP (*A*ssociation-*S*toring *P*rocessor) machine organization,[6.125] and various approaches which compromise somewhat on speed, including bit- rather than word-parallel searching[6.126] or the use of circulating memories such as glass delay lines.[6.127]

Cryogenic approaches to the hardware realization of associative memory concepts have been under investigation since at least the mid-1950's (Slade and McMahon, 1957), while McDermid and Peterson (1961) report work on a magnetic core technique as of 1960. However, the technology for developing high-speed reactivity in these special-purpose memories has been advanced in the past few years. On the basis of experimental demonstration, at least, there have been significant advances with respect to parallel-processing, associative-addressing, internal but auxiliary techniques in the form of memories built-into some of the recently developed large computer systems.[6.128]

The actual incorporation of such devices, even if of somewhat limited scale, in operational computer system designs is of considerable interest, whether of 25- or 250-nanosecond performance. For example, Ammon and Neitzert report RCA experiments that "show the feasibility of a 256-word scratchpad memory with an access time of 30 nanoseconds . . . The read/write cycle time, however, will still be limited by the amplifier recovery so that with the best transistors available it appears that 60 nanoseconds are required". (1965, p. 659). RCA developments also include a sonic film memory in which thin magnetic films and scanning strain waves are combined for serial storage of digital information.[6.129]

Crawford et al. (1965) have claimed that an IBM tunnel diode memory of 64 48-bit words and a read/restore or clear/write cycle time of less than 25 nanoseconds was "the first complete memory system using any type of technology reported in this size and speed range". (p. 636).[6.130] Then there is an IBM development of a read-only, deposited magnetic film memory, having high-speed read capability (*i.e.*, 19ns access time) and promising economics because the technique is amenable to batch fabrication.[6.131] (Matick et al., 1966).

Catt and associates of Motorola describe "an integrated circuit memory containing 64 words of 8 bits per word, which is compatible in respect to both speed and signal level with high-speed current-mode gates. The memory has a nondestructive read cycle of 17 nanoseconds and a write cycle of 10 nanoseconds without cycle overlap." (Catt et al., 1966, p. 315).[6.132] Anacker et al. (1966) discuss 1,000-bit film memories with 30 nanosecond access times.[6.133] Kohn et al. (1967) have investigated a 140,000 bit, nondestructive read-out magnetic film memory that can be read with a 20-nanosecond read cycle time, a 30-nanosecond access time, and a 65-nanosecond write time. More recently, IBM has announced a semi-conductor memory with 40 nanosecond access.[6.134]

Memories of this type that are of somewhat larger capacity but somewhat less speed (in the 100–500 nanosecond range) are exemplified by such commercially-announced developments as those of Electronic Memories,[6.135] Computer Control Company,[6.136] and IBM.[6.137] Thus, Werner et al. (1967) describe a 110-nanosecond ferrite core memory with a word capacity of 8,192 words,[6.138] while Pugh et al. (1967) report other IBM developments involving a 120-nanosecond film memory of 600,000-bit capacity. McCallister and Chong (1966) describe an experimental plated wire memory system of 150,000-bit capacity with a 500-nanosecond cycle time and a 300-nanosecond access time, developed at UNIVAC.[6.139] Another UNIVAC development involves planar thin films.[6.140] A 16,384-word, 52-bit, planar film memory with half-microsecond or less, (350 nanosecond) cycle time, under development at Burroughs laboratories for some years, has been described by Bittman (1964).[6.141] Other recent developments have been discussed by Seitzer (1967)[6.142] and Raffel et al. (1968),[6.143] among others.

For million-bit and higher capacities, recent IBM investigations have been directed toward the use of "chain magnetic film storage elements"[6.144] in both DRO and NDRO storage systems with 500-nanosecond cycle times.[6.145] It is noted, however, that "a considerable amount of development work is still required to establish the handling, assembly, and packaging techniques." (Abbas et al., 1967, p. 311).

A plated wire random access memory is under development by UNIVAC for the Rome Air Development Center. "The basic memory module consists of 10^7 bits; the mechanical package can hold 10 modules. The potential speed is a 1-to-2 microsecond word rate. . . . Ease of fabrication has been emphasized in the memory stack design. These factors, together with the low plated wire element cost, make an inexpensive mass plated wire store a distinct possibility." (Chong et al., 1967, p. 363).[6.146] RADC's interests in associative processing are also reflected in contracts with Goodyear Aerospace Corp., Akron, Ohio, for investigation and experimental fabrication of associative memories and processors. (See, for example, Gall, 1966).

6.3.3. High-Density Data Recording and Storage Techniques

Another important field of investigation with respect to advanced data recording, processing, and storage techniques is that of further development of high-density data recording media and methods and bulk storage techniques, including block-oriented random access memories.[6.147] Magnetic techniques—cores, tapes, and cards—continue to be pushed toward multimillion bit capacities.[6.148] A single-wall domain magnetic memory system has recently been patented by Bell Telephone Laboratories.[6.149] In terms of R & D requirements for these techniques, further development of magnetic heads, recording media, and means for track location has been indicated,[6.150] as is also the case for electron or laser beam recording techniques.[6.151] Videotape developments are also to be noted.[6.152]

In addition to the examples of laser, holographic, and photochromic technologies applied to high density data recording previously given, we may note some of the other advanced techniques that are being developed for large-capacity, compact storage. These developments include the materials and media as well as techniques for recording with light, heat, electrons, and laser beams. In particular, "a tremendous amount of research work is being undertaken in the area of photosensitive materials. Part of this has been sparked by the acute shortage of silver for conventional films and papers. In October, more than 800 people attend a symposium in Washington, D.C., on Unconventional Photographic Systems. Progress was described in a number of areas, including deformable films, electrophotography, photochromic systems, unconventional silver systems, and photopolymers." (Hartsuch, 1968, p. 56).

Examples include the General Electric Photocharge,[6.153] the IBM Photo-Digital system,[6.154] the UNICON mass memory,[6.155] a system announced by Foto-Mem Inc.[6.156] and the use of thin dielectric films at Hughes Research Laboratories.[6.157] At Stanford Research Institute, a program for the U.S. Army Electronics Command is concerned with investigations of high-density arrays of micron-size storage elements, which are addressed by electron beam. The goal is a digital storage density of 10^8 bits per square centimeter.[6.158]

Still another development is the NCR heat-mode recording technique. (Carlson and Ives, 1968). This involves the use of relatively low power CW lasers to achieve real-time, high-resolution (150 : 1) recording on a variety of thin films on suitable substrates.[6.159] In particular, microimage recordings can be achieved directly from electronic character-generation devices.[6.160] Newberry of General Electric has described an electron optical data storage technique involving a 'fly's eye' lens system for which a "a packing density of 10^8 bits per square inch has already been demonstrated with 1 micron beam diameter." (1966, p. 727–728).

Then there is a new recording-coding system, from Kodak, that uses fine-grained photographic media, diffraction grating patterns, and laser light sources.[6.161] As a final example of recent recording developments we note that Gross (1967) has described a variety of investigations at Ampex, including color video recordings on magnetic film plated discs, silver halide film for both digital and analog recordings, and use of magneto-optic effects for reading digital recordings.[6.162]

Areas where continuing R & D efforts appear to be indicated include questions of read-out from highly compact data storage,[6.163] of vacuum equipment in the case of electron beam recording,[6.164] and of noise in some of the reversible media.[6.165] Then it is noted that "at present it is not at all clear what compromises between direct image recording and holographic image recording will best preserve high information density with adequate redundancy, but the subject is one that attracts considerable research interest." (Smith, 1966, p. 1298).

Materials and media for storage are also subjects of continuing R & D concern in both the achievement of higher packing densities with fast direct access and in the exploration of prospects for storage of multivalued data at a single physical location. For example: "A frontal attack on new materials for storage is crucial if we are to use the inherent capability of the transducers now at our disposal to write and read *more* than 1 bit of data at 1 location . . .

"One novel approach for a multilevel photographic store now being studied is the use of color photography techniques to achieve multibit storage at each physical memory location . . . Color film can store multilevels at the *same* point because both intensity and frequency can be detected." (Hoagland, 1965, p. 58).

"An experimental device which changes the color of a laser beam at electronic speeds has been developed . . . IBM scientists believe it could lead to the development of color-coded computer memories with up to a hundred million bits of information stored on one square inch of photographic film." (Commun. ACM **9**, 707 (1966).)

Such components and materials would have extremely high density, high resolution characteristics. One example of intriguing technical possibilities is reported by Fleisher et al. (1965) in terms of a standing-wave, read-only memory where *n* color sources might provide *n* information bits, one for each color, at each storage location.[6.166] These authors claim that an apparently unique feature of this memory would be a capability for storing both digital and analog (video) information,[6.167] and that parallel word selection, accomplished by fiber-optic light splitting or other means, would be useful in associative selection and retrieval.[6.168]

7. Debugging, On-Line Diagnosis, Instrumentation, and Problems of Simulation

Beyond the problems of *initial design* of information processing systems are those involved in the provision of suitable and effective debugging, self-monitoring, self-diagnosis, and self-repair facilities in such systems. Overall system design R & D requirements are, finally, epitomized in increased concern over the needs for on-line instrumentation, simulation, and formal modelling of information flows and information handling processes, and with the difficulties so far encountered in achieving solutions to these problems. In turn, many of these problems are precisely involved in questions of systems evaluation.

It has been cogently suggested that the area of aids to debugging "has been given more lip service and less attention than any other"[7.1] in considerations of information processing systems design. Special, continuing, R & D requirements are raised in the situations, first, of checking out very large programs, and secondly, of carrying out checkout operations under multiple-access, effectually on-line, conditions.[7.2] In particular, the checkout of very large programs presents special problems.[7.3]

7.1. Debugging Problems

Program checkout and debugging are also problems of increasing severity in terms of multiple-access systems. Head states that "testing of many non-real-time systems—even large ones—has all too often been ill-planned and haphazard with numerous errors discovered only after cutover. . . . In most real-time systems, the prevalence of errors after cutover, any one of which could force the system to go down, is intolerable." (1963, p. 41.) Bernstein and Owens (1968) suggest that conventional debugging tools are almost worthless in the time-sharing situation and propose requirements for an improved debugging support system.[7.4]

On-line debugging provides particular challenges to the user, the programmer and the system designer.[7.5] It is important that the console provide versatile means of accomplishing system and program self-diagnosis, to determine what instruction caused a hang-up, to inspect appropriate registers in a conflict situation, and to display anticipated results of a next instruction before it is executed. A major consideration is the ability to provide interpretation and substitution of instructions, with traps, from the console. A recent system for on-line debugging, EXDAMS (*EX*tendable *D*ebugging *a*nd *M*onitoring *S*ystem), is described by Balzer (1969).[7.6]

Aids to debugging and performance evaluation provided by a specific system design should therefore include versatile features for address traps, instruction traps, and other traps specified by the programmer. For example, if SIMSCRIPT programs are to be run, a serious debugging problem arises because of the dynamic storage allocation situation where the clients needs to find out where he is and provide dynamic dumping, e.g., by panel interrupt without halting the machine. Programmers checking out a complex program need an interrupt-and-trap-to-a-fixed location system, the ability to bounce out of a conflict without being trapped in a halt, to jump if a program accesses a particular address, to take special action if a data channel is tied up for expected input not yet received, or to jump somewhere else on a given breakpoint and then come back to scheduled address, e.g., on emergence of an overflow condition.[7.7]

Problems of effective debugging, diagnostic, and simulation *languages* are necessarily raised.[7.8] For example, McCarthy et al. report: "In our opinion the reduction in debugging time made possible by good typewriter debugging languages and adequate access to the machine is comparable to that provided by the use of ALGOL type languages for numerical calculation." (McCarthy et al., 1963, p. 55). Still another debugging and diagnostic R & D requirement is raised with respect to reconfigurations of available installations and tentative evaluations of the likely success of the substitution of one configuration for another.[7.9]

In at least one case, a combined hardware-software approach has been used to tackle another special problem of time-shared, multiple-user systems, that of machine maintenance with minimum interference to ongoing client programs. The STROBES technique (for *S*hared-*t*ime-*r*epair *o*f *b*ig *e*lectronic *s*ystems) has been developed at the Computation Center of the Carnegie Institute of Technology.[7.10] This type of development is of significance because as Schwartz and his co-authors report (1965, p. 16): "Unlike more traditional systems, a time-sharing system cannot stop and start over when a hardware error occurs. During time-sharing, the error must be analyzed, corrected if possible, and the user or users affected must be notified. For all those users not affected, no significant interruption should take place."

7.2. On-Line Diagnosis and Instrumentation

Self-diagnosis is an important area of R & D concern with respect both to the design and the utilization of computer systems.[7.11] In terms of potentials for automatic machine-self-repair, it is noted that "a self-diagnosable computer is a computer which has the capabilities of automatically detecting and isolating a fault (within itself) to a small number of replaceable modules." (Forbes et al., 1965, p. 1073).[7.12] To what extent can the machine itself be used to generate its own programs and procedures? Forbes et al. suggest that: "If the theory of self-diagnosing computers is to become practical for a family of machines, further study and development of machine generation of diagnostic procedures is necessary." (1965, p. 1085).

Several different on-line instrumentation* techniques have been experimentally investigated by Estrin and associates (1967), by Hoffman (1965), Scherr (1965) and by Sutherland (1965), among others.[7.13] Monitoring systems for hardware, software, or both are described, for example, by Aviżiensis (1967, 1968),[7.14] Jacoby (1959),[7.15] and Wetherfield (1966),[7.16] while a monitoring system for the multiplexing of slow-speed peripheral equipment at the Commonwealth Scientific and Industrial Research Organization in Australia is described by Abraham et al. (1966). Moulton and Muller (1967) describe DITRAN (*DI*agnostic FOR*TRAN*), a compiler with extensive error checking capabilities that can be applied both at compilation time and during program execution, and Whiteman (1966) discusses "computer hypochondria".[7.17]

Fine et al. (1966) have developed an interpreter program to analyze running programs with respect to determining sequences of instructions between page calls, page demands by time intervals, and page demands by programs. In relatively early work in this area, Licklider and Clark report that "*Program Graph* and *Memory Course* are but two of many possible schemes for displaying the internal processes of the computer. We are working on others that combine graphical presentation with symbolic representation . . . By combining graphical with symbolic presentation, and putting the mode of combination under the operator's control via light pen, we hope to achieve both good speed and good discrimination of detailed information." (1962, p. 120). However, Sutherland comments that: "The information processing industry is uniquely wanting in good instrumentation; every other industry has meters, gauges, magnifiers—instruments to measure and record the performance of machines appropriate to that industry." (Sutherland, 1965, p. 12). More effective on-line instrumentation techniques are thus urgently required, especially for the multiple-access processing system.

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*"Instrumentation" in this context means diagnostic and monitoring procedures which are applied to operating programs in a "subject" computer as they are being executed in order to assemble records of workload, system utilization, and other similar data.

Huskey supports the contentions of Sutherland and of Amdahl that: "Much more instrumentation of on-line systems is needed so that we know what is going on, what the typical user does, and what the variations are from the norms. It is only with this information that systems can be 'trimmed' so as to optimize usefulness to the customer array." (Huskey, 1965, p. 141).

Sutherland in particular points out that *plots* of times spent by the program in doing various sub-tasks, can tighten up frequently used program and sub-routine loops and thus save significant amounts of processor running-time costs.[7.18] He also refers to a system developed by Kinslow in which a pictorial representation of "which parts of memory were 'occupied' as a function of time for his time-sharing system. The result shows clearly the small spaces which develop in memory and must remain unused because no program is short enough to fit into them." (Sutherland, 1965, p. 13). In general, it is hoped that such on-line instrumentation techniques will bring about better understanding of the interactions of programs and data within the processing system.[7.19]

Improved techniques for the systematic analysis of multiple-access systems are also needed. As Brown points out: "The feasibility of time-sharing depends quite strongly upon not only the time-sharing procedures, but also upon . . . the following properties, characteristic of each program when it is run alone:

(1) The percentage of time actually required for execution of the program . . .
(2) The spectrum of delay times during which the program awaits a human response . . .
(3) A spectrum of program execution burst lengths . . .

A direct measurement of these properties is difficult; a reasonable estimate of them is important, however, in determining the time-sharing feasibility of any given program." (1965, p. 82). However, most of the analyses implied are significantly lacking to date, although some examples of benefits to be anticipated are given by Cantrell and Ellison (1968) and by Campbell and Heffner (1968).

Schwartz et al. emphasize that "another researchable area of importance to proper design is the mathematical analysis of time-shared computer operation. The object in such an analysis is to provide solutions to problems of determining the user capacity of a given system, the optimum values for the scheduling parameters (such as quantum size) to be used by the executive system, and, in general, the most efficient techniques for sequencing the object programs." (Schwartz et al., 1965, p. 21).

Continuing, they point to the use of simulation techniques as an alternative. "Because of the large number of random variables—many of which are interdependent—that must be taken into account in a completely general treatment of time-sharing operation, one cannot expect to proceed very far with analyses of the above nature. Thus, it seems clear that simulation must also be used to study time-shared computer operation." (Schwartz et al., 1965, p. 21). A 1967 review by Borko reaches similar conclusions.[7.20]

7.3. Simulation

The on-going analysis and evaluation of information processing systems will clearly require the further development of more sophisticated and more accurate simulation models than are available today.[7.21] Special difficulties are to be noted in the case of models of multiple access system where "the addition of pre-emptive scheduling complicates the mathematics beyond the point where models can even be formulated" (Scherr, 1965, p. 32) and in that of information selection and retrieval applications where, as has been frequently charged, "no accurate models exist". (Hayes, 1963, p. 284).

In these and other areas, then, a major factor is the inadequacy of present-day mathematical techniques.[7.22] In particular, Scherr asserts that "simulation models are required because the level of detail necessary to handle some of the features studied is beyond the scope of mathematically tractable models." (Scherr, 1965, p. 32). The importance of continuing R & D efforts in this area, even if they should have only negative results, has, however been emphasized by workers in the field.[7.23]

Thus, for example, at the 1966 ACM-SUNY Conference, "Professor C. West Churchman . . . pointed to the very large [computer] models that can now be built, and the very much larger models that we will soon be able to build, and stated that the models are not realistic because the quality of information is not adequate and because the right questions remain unasked. Yet he strongly favored the building of models, and suggested that much information could be obtained from attempts to build several different and perhaps inconsistent models of the same system." (Commun. ACM **9**, 645 (1966).)

We are led next, then, to problems of simulation. There are obvious problems in this area also. First there is the difficulty of "determining and building meaningful models" (Davis, 1965, p. 82), especially where a high degree of *selectivity* must be imposed upon the collection of data appropriately representative of the highly complex real-life environments and processes that are to be simulated.[7.24]

Beyond the questions of adequate selectivity in simulation-representation of the phenomena, operations, and possible system capabilities being modelled are those of the adequacy of the simulation languages as discussed by Scherr, Steel, and others.[7.25] Teichroew and Lubin present a comprehensive survey of computer simulation languages and applications, with tables of comparative characteristics, as of 1966.[7.26] In addition, IBM has provided a bibliography on simulation, also as of 1966.

Again, as in the area of graphic input manipulation and output, the field of effective simulation has specific R & D requirements for improved and more versatile machine models and programming languages. Clancy and Fineberg suggest that "the very number and diversity of languages suggests that the field [of digital simulation languages] suffers from a lack of perspective and direction." (1965, p. 23).

The area of improved simulation languages is one that has a multiple interaction between software and hardware, especially where a computer is to be used to simulate another computer, perhaps one whose design is not yet complete [7.27] or to simulate many different scheduling, queuing and storage allocation alternatives in time-shared systems (see, for example, Blunt 1965). Such problems are also discussed by Scherr (1965) and by Larsen and Mano (1965), among others, while Parnas (1966) describes a modification of ALGOL (SFD-ALGOL, for "System Function Description") applicable to the simulation of synchronous systems.

However, there are difficult current problems in that languages such as SIMSCRIPT do not take advantage of the modularity of many processing systems, that conditional scheduling of sequences of events is extremely difficult [7.28] and that "we are still plagued by our inability to program for simultaneous action, even for the scheduling of large units in a computing system." (Gorn, 1966, p. 232).

In addition, for simulation and similar applications, heuristic or *ad hoc* programming facilities may be required. Thus, "a computer program which is to serve as a model must be able to have well-organized yet manipulatable data storage, easily augmentable and modifiable. The program must be self-modifying in a similarly organized way. It should be able to handle large blocks of data or program routines by specification of merely a name." (Strom, 1965, p. 114.)

For simulations or testings with controls, and without discernible interruption or reallocation of normal servicing of client processing requests, compilers must be available that will transform queries expressed in one or more commonly available customer languages to the language(s) most effectively used by the substituted experimental system and to the format(s) available in a master data base.

Then there are problems in the development of an appropriate "scenario", or sequence of events to be simulated.[7.29] Burdick and Naylor (1966) provide a survey account of the problems of design and analysis of computer simulation experiments.

The problems of effective simulation of complex, interdependent processes are another area of increasing concern. Suppose, for example, that we are seeking to simulate a process in which many separate operations are carried out concurrently or in parallel, and that the simulation technique requires a serial sequencing of these operations. Depending upon the choice of which one of the theoretically concurrent operations is processed first in the sequentializing procedure, the results of the simulation may be significantly different in one case than in another.[7.30]

For example, the SL/1 language being developed at the University of Pisa under Caracciolo di Forino (1965) is based in part on SOL (Simulation-Oriented Language, see Knuth and McNeley, 1964) and in part on SIMULA (the ALGOL extension developed by O. J. Dahl, of the Norwegian Computing Center, Oslo).[7.31] A second version, SL/2, now under development, will provide self-adapting features to optimize the system. Caracciolo emphasizes that, for any set of deterministic processes that are to be applied simultaneously, but where problems of incompatibility may arise, the problems can be reduced to a set of *probabilistic* processes. Otherwise, if one sequentializes parallel, concurrent processes actually dependent upon the order of sequentialization, then hidden problems of incompatibility may vitiate the results obtained.

Despite difficulties, however, progress has been and is being made. Thus computer simulation has been investigated as a means of system simulation for determination of probable costs and benefits in advance of major investments in equipment or procedures.[7.32] Then, as reported by Gibson (1967), simulation studies have been used to determine that block transfers of 4 to 16 words will facilitate reduction of effective internal access times to a few nanoseconds. Other programs to simulate digital data processing, time-shared system performance, and the like, are discussed by Larsen and Mano (1965) and by Scherr (1965). Simulation studies in terms of multiprocessor systems are represented by Lindquist et al. (1966) [7.33] and by Huesmann and Goldberg (1967).[7.34]

Other advantages from research and development efforts to be anticipated from computer simulation experiments are those of transfer of applications from a given computer to another not yet installed or available,[7.35] advancements in techniques of pictorial data processing and transmission,[7.36] advance appraisals of performance of time-shared systems,[7.37] and investigations of probable performance of adaptive recognition systems.[7.38]

Finally, we note prospects for system simulation as a means of evaluation and of redesign, including the alteration of scheduling priorities to meet changing requirements of the system's clientele. Three examples from the literature are as follows:

(1) "Use of a simulator permits the installation to continue running its programs as reprogramming proceeds on a reasonable schedule." (Trimble, 1965, p. 18).

(2) "Effective response time simulation can be

easily modified to provide operating costs of retrieval." (Blunt, 1965, p. 9).

(3) "When large systems are being developed another set of programs is involved to perform a function not required for simpler situations. These are the simulation and analysis programs for system evaluation and—for semi-automated systems having a human component—system training." (Steel, 1965, p. 232).

On the other hand, as Davis warns: "It is obvious that there is some threshold beyond which the real environment is too complex to permit meaningful simulation." (1965, p. 82). For the future, therefore, a system of multiple-working-hypotheses might well be developed: "The benefits and drawbacks of empirical data gathering vs. simulation vs. mathematical analysis are well documented. What we would really like to be able to do is a little of all three, back and forth, until our gradually increasing comprehension of the problem becomes the desired solution." (Greenberger, 1966, p. 347). Similarly, it may be claimed that simulation models ". . . are often cumbersome and difficult to adapt to new configurations, with results of somewhat uncertain interpretation due to statistical sampling variability. Ideally, simulation and analytic techniques should supplement each other, for each approach has its advantages." (Gaver, 1967, p. 423).

8. Conclusions

As we have seen, major trends in input/output, storage, processor, and programming design relate to multiple access, multiprogrammed, and multiprocessor systems. On-line simulation, instrumentation, and performance evaluation capabilities are necessary in order to effectively measure and test proposed techniques, systems, and networks of broad future significance to improved utilization of automatic data processing techniques.

We may therefore close this report on overall system design considerations with the following quotations:

(1) "In rating the completeness, clarity, and simplicity of the system diagnostics, command language and keyboard procedures, we found their 'goodness' was inversely related to the running efficiency of the system . . . System developers should examine this condition to determine whether inefficient execution is an inherent feature of system[s] supplying complete and easily understood diagnostics, or a function of the specific interests and prejudices of the developers." (O'Sullivan, 1967, p. 170).

(2) "An engineer who wishes to concern himself with performance criteria in the synthesis of new systems is frustrated by the weakness of measurement of computer system behavior." (Estrin et al., 1967, p. 645.)

(3) "The setting up of criteria of evaluation . . . demands user participation and provides an indication of whether the user understands the reason for the system, the role of the system and his responsibilities as a prospective system user." (Davis, 1965, p. 82.)

(4) "Today, and to an even greater extent tomorrow, the use of multiple functional units within the information processing system, the multiplexing of input and output messages, and the increased use of software to permit multiprogramming will require more subtle measures to evaluate a particular system's performance." (Nisenoff, 1966, p. 1828.)

(5) "Broad areas for further research are indicated . . . Comparative experimental studies of computer facility performance, such as online, offline, and hybrid installations, systematically permuted against broad classes of program languages (machine-oriented, procedure-oriented, and problem-oriented languages), and representative classes of programming tasks." (Sackman et al., 1968, p. 10), and

(6) "Improved methods of simulation, optimizing techniques, scheduling algorithms, methods of dealing with stochastic variables, these are the important developments that are pushing back the limits of our ability to deal with very large systems." (Harder, 1968, p. 233.)

Finally we note that the problems of the information processing system designer, then, are today aggravated not only by networking, time-sharing, time-slicing, multiprocessor and multiprogramming potentialities, but also by critical questions involving the values and the costs of maintaining the integrity of *privileged* files. By the terminology "privileged files", we suggest the interpretation of all data stored in a machine-useful system that may have varying degrees of privacy, confidentiality, or security restrictions placed upon unauthorized access. Some of the background considerations affecting both policy and design factors will be discussed in the next report in this series.

Appendix A. Background Notes on Overall System Design Requirements

In this Appendix we present further discussion and background material intended to highlight currently identifiable research and development requirements in the broad field of the computer and information sciences, with emphasis upon overall system design considerations with respect to information processing systems. A number of illustrative examples, pertinent quotations from the literature, and references to current R and D efforts have been assembled. These background notes have been referenced, as appropriate, in the summary text.

1. Introduction

1.1 There are certain obvious difficulties with respect to the organization of material for a series of reports on research and development requirements in the computer and information sciences and technologies. These problems stem from the overlaps between functional areas in which man-machine interactions of both communication and control are sought; the techniques, tools, and instrumentation available to achieve such interactions, and the wide variety of application areas involved.

The material that has been collected and reviewed to date is so multifaceted and so extensive as to require organization into reasonably tractable (but arbitrary) subdivisions. Having considered some of the R and D requirements affecting specific Boxes shown in Figure 1 (p. 2) in previous reports, we will discuss here some of the overall system design considerations affecting more than one of the processes or functions shown in Figure 1.

Other topics to be covered in separate reports in this series will include specific problems of information storage, selection and retrieval systems and the questions of maintaining the integrity of privileged files (i.e., some of the background considerations with respect to the issues of privacy, confidentiality, and/or security in the case of multiply-accessed, machine-based files, data banks, and computer-communication networks).

In general, the plan of attack in each individual report in the series will be to outline in relatively short discursive text the topics of concern, supplemented by background notes and quotations and by an appendix giving the bibliographic citations of quoted references. It is planned, however, that there will be a comprehensive summary, bibliography, and index for the series as a whole.

Since problems of organization, terminology, and coverage have all been difficult in the preparation of this series of reports, certain disclaimers and observations with respect to the purpose and scope of this report, its necessary selectivity, and the problems of organization and emphasis are to be noted. Obviously, the reviewer's interests and limitations will emerge at least indirectly in terms of the selectivity that has been applied.

In general, controversial opinions expressed or implied in any of the reports in this series are the sole responsibility of the author(s) of that report and are not intended in any way to represent the official policies of the Center for Computer Sciences and Technology, the National Bureau of Standards, or the Department of Commerce. However, every effort has been made to buttress potentially controversial statements or implications either with direct quotations or with illustrative examples from the pertinent literature in the field.

It is especially to be noted that the references and quotations included in the text of this report, in the corroborative background notes, or in the bibliography, are necessarily highly selective. Neither inclusion nor citation is intended in any way to represent an endorsement of any specific commercially available device or system, of any particular investigator's results with respect to those of others, or of the objectives of projects that are mentioned. Conversely, omissions are often inadvertent and are in no sense intended to imply adverse evaluations of products, materials and media, equipment, systems, project goals and project results, or of bibliographic references not included.

There will be quite obvious objections to this necessary selectivity from readers who are also R & D workers in the fields involved as to the representativeness of cited contributions from their own work or that of others. Such criticisms are almost inevitable. Nevertheless, these reports are not intended to be state-of-the-art reviews as such, but, rather, they are intended to provide provocative suggestions for further R & D efforts. Selectivity must also relate to a necessarily arbitrary cut-off date in terms of the literature covered.

These reports, subject to the foregoing *caveats*, are offered as possible contributions to the understanding of the general state of the art, especially with respect to long-range research possibilities in a variety of disciplines that are potentially applicable to information processing problems. The reports are therefore directed to a varied audience among whom are those who plan, conduct, and support research in these varied disciplines. They are also addressed to applications specialists who may hope eventually to profit from the results of current research efforts. Inevitably, there must be some repetitions of the obvious or over-simplifications of certain topics for some readers, and there must also be some too brief or inadequately explained discussions on other topics for these and other readers. What is at best tutorial for one may be difficult for another to follow. It is hoped, however, that the notes and bibliographic citations will provide sufficient clues for further follow-up as desired. The literature survey upon which this report is based generally covered the period from mid-1962 to mid-1968, although a few earlier and a few later references have also been included as appropriate.

1.2 Certain features of the information flow and and process schema of Figure 1 are to be noted. It is assumed, first, that the generalized information processing system should provide for automatic access from and to many users at many locations. This implies multiple inputs in parallel, system interruptibility, and interlacings of computer programs. It is assumed, further, that the overall scheme involves hierarchies of systems, devices and procedures, that processing involves multistep operations, and that multimode operation is possible, depending on job requirements, prior or tentative results, accessibility, costs, and the like.

It should be noted, next, that techniques suggested for a specific system may apply to more than one operational box or function shown in the generalized diagram of Figure 1. Similarly, in a specific system, the various operations or processes may occur in different sequences (including iterations) and several different ones may be combined in various ways. Thus, for example, questions of remote console design may affect original item input, input of processing service requests, output, and entry of feedback information from the user or the system client. The specific solutions adopted may be implemented in each of these operational areas, or combined into one, e.g., by requiring all imputs and outputs to flow through the same hardware.

2. Requirements and Resources Analysis

2.1 "The single information flow concept . . . is input-oriented. The system is organized so that essential data are inserted into a common reservoir through point-of-origin input/output devices. User requirements are then satisfied from this reservoir of fundamental data about transactions.

"Thus, the single information flow concept is characterized by random entry of data, direct access to data in the system, and complete real-time processing . . . fast response, a high degree of reliability, and an easily expansible system." (Moravec, 1965, p. 173).

2.2 "In a highly distributed system, however, information on inputs to the organization flow directly to relatively low-level way stations where all possible processing is done and all actions are taken that are allowed by the protocol governing that level. In addition to the direct actions that it takes, the lowest, or reflexive, level of information processing ordinarily generates two classes of information. These are, first, summaries of actions taken or anticipated and, second, summaries of information inputs that, because of their type, salience, or criticality, fall outside the range of action that policy has established as appropriate for that level. . . .

"In computer terms, a highly distributed system involves a primary executive program that adds and subtracts subroutines to various primary libraries from which alternative subroutines are to be drawn and combined. Secondary executive programs, responding to separate inputs and conditions, select and organize subroutines from each of these primary libraries and add and subtract subroutines to various secondary libraries from which tertiary executive programs select alternative subroutines for use at their level and for controlling the library one level down, and so forth. The flexibility of a distributed system is an outgrowth of the ability of each of the lower executive programs to organize its program on the basis of separate inputs reaching it directly." (Bennett, 1964, pp. 104–106).

"By a distributed implementation of an information service system we mean that the data processing activity is carried out by several or many installations . . . The data base is now distributed among the installations making up the information network for this service system . . .

"The distributed information network should offer considerable advantage in reducing the cost of terminal communications by permitting installations to be located near concentrations of terminals." (Dennis, 1968, p. 373).

2.3 "A large number of factors (user communities, document forms, subject disciplines, desired services, to name but a few) compete for the attention of the designer of information service systems. A methodology for the careful organization of these factors and the orderly consideration of their relationships is essential if intelligent decisions are to be made." (Sparks et al., 1965, pp. 1–2).

"The lack of recognition of the nature and even, in some cases, the existence of the problems facing the information systems designer has meant that there has been little or no orderly development of generally agreed upon system methodology." (Hughes Dynamics, 1964, p. 1–7).

"To the best of our knowledge, no one has yet developed a completely satisfactory theory of information processing. Because there is no strong theoretical basis for the field, we must rely on intuition, experience and the application of heuristic notions each time we attempt to solve a new information processing problem." (Clapp, 1967, p. 4).

2.4 Additional examples are as follows:

"Preliminary data support the previous indications (Werner, Trueswell, *et al.*) that the introduction of new services is not followed by an immediately high level use of them. The state-of-the-art of equipment, personnel, and documentation still offers continuing problems. Medical researchers in the study do not seem to look upon the system as being an essential source of information for their work, but as a convenient ancillary activity." (Rath and Werner, 1967, p. 62).

"A major study recently conducted by Auerbach Corporation into the manpower trends in the engineering support functions concerned with information . . . which involved investigations of a large number of company and government operations, was both surprising and disconcerting because it showed that there are large areas of both government and industry in which there is very little concern about, or work underway toward, solving the information flow and utilization problem." (Sayer, 1965, p. 24).

2.5 "There are seven properties of a system that can be stated explicitly by the organization requesting the system design: WHAT the system should be, WHERE the system is to be used, and WHERE, WHEN, WITH WHAT, FOR WHOM, and WITH WHOM the system is to be designed." (Davis, 1964, p. 20).

2.6 Consider also the following:

"Consequently, it appears that two early areas of required investigation are those of determining: 1) who are the potential users of science and/or engineering information systems, where are they located, what is their sphere of activity? and 2) What is the real nature and volume of material that will flow through a national information system? . . .

"In undertaking a program to establish information service networks it is necessary to know:

1. Who are the users?
2. What are the user information needs?
3. Where are these users?
4. How many users and user groups are there, and how do their needs differ?
5. What information products and services will meet these needs?
6. What production operations are necessary to produce these information products and services?
7. Which of these products and services are really being produced now; by whom and where and how well is an ultimate purpose already being achieved?
8. How will any new system best integrate with existing practices?
9. What are the operations best performed from a standpoint of quality and timeliness of service to users, economy of costs and overall network operations, available trained manpower, and ability to respond to change?" (Sayer, 1965, pp. 144–145).

"Some of the details the user must determine are the number and location of remote points, frequency of use, response time required, volume of data to be communicated, on line storage requirements, and the like." (Jones, 1965, p. 66).

2.7 "Neglect of 'WHERE the system is to be used' is the most frequent cause of inadequate system designs." (Davis, 1964, p. 21).

2.8 Thus Sayer points out the need for "population figures describing the user community in detail, its interest in subject disciplines, and the effect of this interest on the effective demand on the system from both initiative and responsive demands." (Sayer, 1965, p. 140).

Sparks et al. raise the following considerations: "There are certain basic dimensions of an information service system which it is appropriate to recognize in a formal way. One of these is the spectrum of selected disciplines which are to be represented in the information processed by the system. Another of these is the geographical area to be served by the system and in which the user population will be distributed . . .

"The number of user communities into which the user population is divided determines (or is determined by) the number of direct-service information centers in the system. Thus, it has a major effect on system size and structure." (Sparks et al., 1965, pp. 2–6, 2–7).

2.9 "In structuring shiny, new information systems, we must be careful to allow for resistance to change long before the push buttons are installed, especially when the users of the systems have not been convinced that there is a real need for change." (Aines, 1965, p. 5.)

"Examine the various systems characteristics such as: user/network interface; network usage patterns; training requirements; traffic control; service and organization requirements; response effectiveness; cost determinations; and network capacity." (Hoffman, 1965, p. 90–91.)

"As an appendage to a prototype network, some experimental retraining programs would be well advised . . .

"A massive effort directed at retraining large numbers of personnel now functioning in libraries will be required to produce the manpower necessary for a real-time network ever to reach a fully operational status." (Brown et al., 1967, p. 68).

"Where do experimental studies of user performance fit into burgeoning information services? The answer is inescapable: the extent of experimental activity will effectively determine the level of excellence, in method and in substantive findings, with which key problems regarding user performance will be met. If experimental studies in man-computer communication continue to be virtually nonexistent, the gap in verified knowledge of user behavior will continue to be dominated by immediate cost and narrow technical considerations rather than by the users' long range interests. Everyone will be a loser. Neither the managers of computer utilities, or the manufacturers, or the designers of central systems will have tested, reliable knowledge of what the user needs, how he behaves, how long it takes him to master new services, or how well he performs. In turn, the user will not have reliable, validated guidance to plan, select, and become skilled in harnessing the information services best suited to his needs, his time, and his resources. Since he is last, the user loses most." (Sackman, 1968, p. 351).

2.10 "Everyone talks about the computer user, but virtually no one has studied him in a systematic, scientific manner. There is a growing experimental lag between verified knowledge about users and rapidly expanding applications for them. This experimental lag has always existed in computer technology. Technological innovation and aggressive marketing of computer wares have consistently outpaced established knowledge of user performance—a bias in computer technology largely attributable to current management outlook and practice. With the advent of time-sharing systems, and with the imminence of the much-heralded information utility, the magnitude of this scientific lag may have reached a critical point. If unchecked, particularly in the crucial area of software management, it may become a crippling humanistic lag—a situation in which both the private and the public use of computers would be characterized by overriding concern for immediate machine efficiency and economy, and by an entrenched neglect of human needs, individual capabilities, and long-range social responsibilities." (Sackman, 1968, p. 349).

"Quite often the most important parameter in a system's performance is the behavior of the average user. This information is very rarely known in advance, and can only be obtained by gathering statistics. It is important to know, for example, how long a typical user stays on a time-sharing system during an average session, how many language processors he uses, how much computing power he requires during each 'interaction' with the system, and so forth. Modeling and simulation can be of great help in pre-determining this information if the environment is known, but in many commercial or University time-sharing systems there is little control over or prior knowledge of the characteristics of the users." (Yourdon, 1969, p. 124).

"The lag in user studies is a heritage which stems mainly from the professional mix that originally developed and used the technology of man-computer communications. For two critical, formative decades, the 1940's and the 1950's—comprising the birth and development of electronic digital computers—social scientists, human engineers and human factors specialists, the professionals trained to work with human subjects under experimental conditions, were only indirectly concerned with man-computer communications, dealing largely with knobs, buttons and dials rather than with the interactive problem-solving of the user. In all fairness, there were some exceptions to this rule, but they were too few and too sporadic to make a significant and lasting impact on the mainstream of user development. Since there was, in effect, an applied scientific vacuum surrounding man-computer communication, it is not at all surprising that there does not exist today a significant, cumulative experimental tradition for testing and evaluating computer-user performance." (Sackman, 1968, p. 349).

"The problem is, of course, to get the right information to the right man at the right time and at his work station and with minimum effort on his part. What all this may well be saying is that the information problem that exists is considerably more subtle and complex than has been set forth . . . The study for development of a Methodology for Analysis of Information Systems Networks arrives, both directly and by implication at the same conclusion as have a number of other recent studies. That conclusion is that much more has to be known about the user and his functions, and much more has to be known about what the process of RDT & E actually is and how can information, as raw material input to the process, flow most efficiently and most effectively." (Sayer, 1965, p. 146).

"The recurrent theme in general review articles concerned with man-computer communication is the glaring experimental lag. Innovation and unverified applications outrace experimental evaluation on all sides.

"In a review of man-computer communication, Ruth Davis points out that virtually no experimental work has been done on user effectiveness. She characterizes the status of user statistics as inadequate and 'primitive', and she urges the specification and development of extensive measures of user performance. . . .

"Pollack and Gildner reviewed the literature on user performance with manual input devices for man-computer communication. Their extensive survey—covering large numbers and varieties of switches, pushbuttons, keyboards and encoders—revealed 'inadequate research data establishing performance for various devices and device characteristics, and incomplete specification of operator input tasks in existing systems.' There was a vast experimental gap between the literally hundreds of manual input devices surveyed and the very small subset of such devices certified by some form of user validation. They recommended an initial program of research on leading types of task/device couplings, and on newer and more natural modes of manual inputs such as speech and handwriting." (Sackman, 1968, p. 350).

2.11 "Information control at input can be used to achieve improved system efficiency in several different ways. First, a reduction in the *total* *volume* of information units or reports to be received, processed, or stored can be gained through the use of filtering procedures to reduce the possible redundancies between items received. (Timing considerations are important in such procedures, as noted elsewhere, because we won't want a delayed and incorrect message to 'update' its own correction notice.)

"Secondly, input filtering procedures serve to reduce the *total bulk* of information to be processed or stored—both by elimination of duplicate items as such and by the compression of the quantitative amount of recording used to represent the original information unit or message within the system.

"A third technique of information control at input is directed to the control of redundancy within a single unit or report. Conversely, input filtering procedures of this type can be used to *enhance* the value of information to be stored. For example, in pictorial data processing, automatic boundary contrast enhancements or 'skeletonizations' may improve both subsequent human pattern perception and system storage efficiency. Another example is natural text processing, where systematic elimination of the 'little', 'common', and 'non-informing' words can significantly reduce the amount of text to be manipulated by the machine." (Davis, 1967, p. 49).

2.12 In this area, R & D requirements for the future include the very severe problems of sifting and filtering enormous masses of remotely collected data. For example, "our ability to acquire data is so far ahead of our ability to interpret and manage it that there is some question as to just how far we can go toward realizing the promise of much of this remote sensing. Probably 90% of the data gathered to date have not been utilized, and, with large multi-sensor programs in the offing, we face the danger of ending up prostrate beneath a mountain of utterly useless films, tapes, and charts." (Parker and Wolff, 1965, p. 31).

2.13 "Purging because of redundancy is extremely difficult to accomplish by computer program except in the case of 100% duplication. Redundancy purging success is keyed to practices of standardization, normalization, field formatting, abbreviation conventions and the like. As a case in point, document handling systems universally have problems with respect to bibliographic citation conventions, transliterations of proper names, periodical title abbreviations, corporate author listing practices and the like." (Davis, 1967, p. 20).

See also Ebersole (1965), Penner (1965), and Sawin (1965) who points to some of the difficulties with respect to a bibliographic collection or file, as follows:

"1. Actual errors, such as incorrect spelling of words, incorrect report of pagination, in one or more of the duplicates. The error may be mechanically or humanly generated; the error may have been made in the source bibliography, or by project staff in transcription from source to paper tape. In any case, error is a factor in reducing the possibility of identity of duplicates.

"2. Variations among bibliographies both in style and content. A bibliographical citation gives several different kinds of information; that is, it contains several 'elements,' such as author of item, title, publication data, reviews and annotations. Each source bibliography more or less consistently employs one style for expressing information, but each style differs from every other in some or all of the following ways:

a. number of elements
b. sequence of elements
c. typographical details" (1965, p. 96).

2.14 "File integrity can often be a significant motivation for mechanization. To insure file integrity in airline maintenance records, files have been republished monthly in cartridge roll-microfilm form, since mechanics would not properly insert update sheets in maintenance manuals. Freemont Rider's original concept for the microcard, which was a combination of a catalog card and document in one record, failed in part because of the lack of file integrity. Every librarian knows that if there wasn't a rod through the hole in the catalog card they would not be able to maintain the integrity of the card catalog." (Tauber, 1966, p. 277).

2.15 "Retirement of outmoded data is the only long-range effective means of maintaining an efficient system." (Miller et al., 1960, p. 54).

With respect to maintenance processes involving the deletion of obsolete items, there are substantial fact finding research requirements for large-scale documentary item systems in terms of establishing efficient but realistic criteria for "purging". Kessler comments on this point as follows: "It is not just a matter of throwing away 'bad' papers as 'good' ones come along. The scientific literature is unique in that its best examples may have a rather short life of utility. A worker in the field of photoelectricity need not ordinarily be referred to Einstein's original paper on the subject. The purging of the system must be based on criteria of operational relevance rather than intrinsic value. These criteria are largely unknown to us and represent another basic area in need of research and invention." (1960, pp. 9–10).

"Chronological cutoff is that device attempted most frequently in automated information systems. It is employed successfully in real-time systems such as aircraft or satellite tracking or airline reservations systems where the information is useless after very short time intervals and where it is so voluminous as to be prohibitive for future analyses . . .

"That purging which is done is primarily *replacement*. Data management or file management systems are generally programmed so that upon proper identification of an item during the manual input process it may replace an item already in the system data bank. The purpose of replacement as a purging device is not volume control. It is for purposes of accuracy, reliability or timeliness controls." (Davis, 1967, p. 15).

"The reluctance to purge has been a leading reason for accentuating *file storage hierarchy considerations. Multi-level deactivation* of information is substituted for purging. Deactivation proceeds through allocating the material so specified first to slower random-access storage devices and then to sequentially-accessed storage devices with decreasing rates of access all on-line with the computer. As the last step of deactivation the information is stored in off-line stores . . .

"Automatic purging algorithms have been written for at least one military information system and for SDC's time-sharing system . . . In the military system . . . the purging program written allowed all dated units of information to be scanned and those prior to a prescribed date to be deleted and transcribed onto a magnetic tape for printing. The information thus nominated for purging was reviewed manually. If the programmed purge decision was overridden by a manual decision the falsely purged data then had to be re-entered into system files as would any newly received data." (Davis, 1967, pp. 16–18).

"Automatic purging algorithms have been explored for the past three years. The current scheme attempts to dynamically maintain a 10 percent disc vacancy factor by automatically deleting the oldest files first. User options are provided which permit automatic dumping of files on a backup, inactive file tape . . . prior to deletion." (Schwartz and Weissman, 1967, p. 267).

"The newer time-sharing systems contemplate a hierarchy of file storage, with 'percolation' algorithms replacing purging algorithms. Files will be in constant motion, some moving 'down' into higher-volume, slower-speed bulk store, while others move 'up' into lower-volume, higher-speed memory—all as a function of age and reference frequency." (Schwartz and Weissman, 1967, p. 267).

2.16 "Some computer-oriented statistics are provided to assist in monitoring the system with minimum cost or time. Such statistics are tape length and length of record, checks on dictionary code number assignment, frequency of additions or deletions to the dictionary, and checks to see that the correct inverted file was updated." (Smith and Jones, 1966, p. 190).

"Usage statistics as obsolescence criteria are commonly employed in scientific and technical information systems and reference data systems . . .

"Usage statistics are also used in the deactivation process to organize file data in terms of its reference frequency. The Russian-to-English automated translation system at the Foreign Technology Division, Wright-Patterson AFB had its file system organized on this basis by IBM in the early 1960's. It was found from surveys of manual translators that the majority of vocabulary references were to less than one thousand words. These were isolated and located in the fastest-access memory; the rest of the dictionary was then relegated to lower priority locations . . ." (Davis, 1967, pp. 18–19).

"The network might show publications being permanently retained at a particular location. This would allow others in the network to dispose of little-used materials and still have access to a copy if the unexpected need arose . . .

"Such an 'archival' copy could, of course, be relocated to a relatively low-cost warehouse area for the mutual benefit of those agencies in the network. Statistics on frequency of usage might be very helpful in identifying inactive materials, and the network could also fill this need." (Brown et al., 1967, p. 66).

"Periodic reports to users on file activity may reveal possible misuse or tampering." (Petersen and Turn, 1967, p. 293).

2.17 "*Accessibility.* For a system output a measure of how readily the proper information was made available to the requesting user on the desired medium." (Davis, 1964, p. 469).

2.18 Consider also the following:

"The system study will consider that the document-retrieval problem lies primarily within the parameters of file integrity; activity and activity distribution; man-file interaction; the size, nature and organization of the file; its location and work-place layout; whether it is centralized or decentralized; access cycle time; and cost. Contributing factors are purging and update; archival considerations; indexing; type of response; peak-hour, peak-minute activity; permissible-error rates; and publishing urgency." (Tauber, 1966, p. 276).

Then there are questions of sequential decision-making and of time considerations generally. "Time consideration is explicitly, although informally, introduced by van Wijngaarden as 'the value of a text so far read'. Apart from other merits of van Wijngaarden's approach and his stressing the interaction between syntax and semantics, we would like to draw attention to the concept of 'value at time t', which seems to be a really basic concept in programming theory." (Caracciolo di Forino, 1965, p. 226). We note further that "T as the time a fact assertion is reported must be distinguished from the time of the fact history referred to by the assertion." (Travis, 1963, p. 334).

Avram et al., point more prosaically to practical problems in mechanized bibliographic reference data handling, as in the case of different types of searches on date: The case of requesting all works on, say, genetics, written since 1960 as against that of all works on genetics published since 1960 with respect to post-1960 reprints of pre-1960 original texts.

For the future, moreover, "In some instances, the search request would have to take into account which data has been used in the fixed field. For example, should one want a display of all the books in Hebrew published during a specific time frame, an adjustment would have to be made to the date in the search request to compensate for the adjustment made to the data at input time." (Avram et al., 1965, p. 42).

2.19 "Here you run into the phenomenon of the 'elastic ruler'. At the time when certain data were accumulated, the measurements were made with a standard inch or standard meter . . . whether researchers were using an inch standardized before a certain date, or one adopted later." (Birch, 1966, p. 165).

2.20 "Large libraries face the problem of converting records that exist in many languages. The most complete discussion of this problem to date is by Cain & Jolliffe of the British Museum. They suggest methods for encoding different languages and speculate on the extent to which certain transliterations could be done by machine. The possibility of storing certain exotic languages on videotapes is suggested as a way of handling the printing problem. At the Brasenose Conference at which this paper was presented, the authors analyzed the difficulties in bibliographic searching caused by transliteration of languages (this is the scheme most generally suggested by those in the data processing field)." (Markuson, 1967, p. 268).

2.21 "The question of integrity of information within an automated system is infrequently addressed." (Davis, 1967, p. 13).

"No adequate reference service exists that would allow users to determine easily whether or not records have the characteristics of quality and compatibility that are appropriate to their analytical requirements." (Dunn, 1967, p. 22).

2.22 "Controls through 'common sense' or logical checks . . . include the use of allowable numerical bounds such as checking bearings by assuming them to be bounded by 0° as a minimum and 360° as a maximum. They include consistency checks using redundant information fields such as social security number matched against aircraft type and aircraft speed. They also include current awareness checks such as matches of diplomat by name against reported location by city against known itinerary against known political views." (Davis, 1967, p. 26).

"A quite different kind of work is involved in examining for internal consistency the reports from the more than 3 million establishments covered in the 1954 Censuses of Manufactures and Business. If these reports were all complete and self-consistent and if we were smart enough to foresee all the problems involved in classifying them, and if we made no errors in our office work, the job of getting out the Census reports would be laborious but straightforward. Unfortunately, some of the reports do contain omissions, errors, and evidence of misunderstanding. By checking for such inconsistencies we eliminate, for example, the large errors that would result when something has been improperly reported in pounds instead of in thousands of pounds. Perhaps one-third to one-half of the time our UNIVACs devote to processing these Censuses will be spent checking for such inconsistencies and eliminating them. . . .

"Similar checking procedures are applied to the approximately 7,000 product lines for which we have reports. In a like manner we check to see whether such relationships as annual man hours and number of production workers, or value of shipments and cost of labor and materials, are within reasonable limits for the industry and area involved. . . .

"For example, the computer might determine for an establishment classified as a jewelry repair shop, that employees' salaries amounted to less than 10 percent of total receipts. For this kind of service trade, expenditures for labor usually represent the major item of expenses and less than 10 percent for salaries is uncommonly low. Our computer would list this case for inspection, and a review of the report might result in a change in classification from 'jewelry repair shop to retail jewelry store', for example." (Hansen and McPherson, 1956, pp. 59–60).

2.23 "The use of logical systems for error control is in beginning primitive stages. Question-answering systems and inference-derivation programs may find their most value as error control procedures rather than as query programs or problem-solving programs." (Davis, 1967, p. 47).

"A theoretically significant result of introducing source indicators and reliability indicators to be carried along with fact assertions in an SFQA [question-answering] system is that they provide a basis for applying purifying programs to the fact assertions stored in the system—i.e., for resolving contradictions among different assertions, for culling out unreliable assertions, etc. . . .

"Reliability information might indicate such things as: *S*'s degree of confidence in his own report if *S* is a person; *S*'s probable error if *S* is a measuring instrument; *S*'s dependability as determined by whether later experience confirmed *S*'s earlier reports; conditions under which *S* made its report, etc." (Travis, 1963, p. 333).

2.24 "Another interesting distinction can be made between files on the basis of their accuracy. A clean file is a collection of entries, each of which was precisely correct at the time of its inclusion in the file. On the other hand, a dirty file is a file that contains a significant portion of errors. A recirculating file is purged and cleansed as it cycles—a utility-company billing file is of this nature. After the file 'settles down,' the proportion of errors imbedded in the file is a function of the new activity applied to the file. The error rate is normalized with respect to the business cycle." (Patrick and Black, 1964, p. 39).

"When messages are a major source of the information entering the system corrections to a previously transmitted original message can be received before the original message itself. If entered on an earlier update cycle the correction data can actually be 'corrected' during a later update cycle by the original incorrect message." (Davis, 1967, p. 24).

2.25 "Errors will occur in every data collection system, so it is important to detect and correct as many of the errors as possible." (Hillegass and Melick, 1967, p. 56).

"The primary purpose of a data communications system is to transmit useful information from one location to another. To be useful, the received copy of the transmitted data must constitute an accurate representation of the original input data, within the accuracy limits dictated by the application requirements and the necessary economic tradeoffs. Errors will occur in every data communications system. This basic truth must be kept in mind throughout the design of every system. Important criteria for evaluating the performance of any communications system are its degree of freedom from data errors, its probability of detecting the errors that do occur, and its efficiency in overcoming the effects of these errors." (Reagan, 1966, p. 26).

"The form of the control established, as a result of the investigation, should be decided only after considering each situation in the light of the three control concepts mentioned earlier. Procedures, such as key verification, batch totals, sight verification, or printed listings should be used only when they meet the criteria of reasonableness, in light of the degree of control required and the cost of providing control in relation to the importance and volume of data involved. The objective is to establish appropriate control procedures. The manner in which this is done—i.e., the particular combination of control techniques used in a given set circumstances—will be up to the ingenuity of the individual systems designer." (Baker and Kane, 1966, pp. 99–100).

2.26 "Two basic types of codes are found suitable for the burst type errors. The first is the forward-acting Hagelbarger code which allows fairly simple data encoding and decoding with provisions for various degrees of error size correction and error size detection. These codes, however, involve up to 50 percent redundancy in the transmitted information. The second code type is the cyclic code of the Bose-Chaudhuri type which again is fairly simple to encode and can detect various error burst sizes with relatively low redundancy. This code type is relatively simple to decode for error detection but is too expensive to decode for error correction, and makes retransmission the only alternative." (Hickey, 1966, p. 182).

2.27 "Research devoted to finding ways to further reduce the possibility of errors is progressing on many fronts. Bell Telephone Laboratories is approaching the problem from three angles: error detection only, error detection and correction with a non-constant speed of end-to-end data transfer (during the correction cycle transmission stops), and error detection and correction with a constant speed of end-to-end data transfer (during the correction cycle transmission continues)." (Menkhaus, 1967, p. 35).

"There are two other potential 'error injectors' which should be given close attention, since more control can be exercised over these areas. They are: the data collection, conversion and input devices, and the human being, or beings, who collect the data (or program a machine to do it) at the source. Bell estimates that the human will commit an average of 1,000 errors per million characters handled, the mechanical device will commit 100 per million, and the electronic component, 10 per million. . . .

"Error detection and correction capability is a 'must' in the Met Life system and this is provided in several ways. The input documents have Honeywell's Orthocode format, which uses five rows of bar codes and several columns of correction codes that make defacement or incorrect reading virtually impossible; the control codes also help regenerate partially obliterated data. . . .

"Transmission errors are detected by using a dual pulse code that, in effect, transmits the signals for a message and also the components of those signals, providing a double check on accuracy. The paper tape reader, used to transmit data, is bi-directional; if a message contains a large number of errors, due possibly to transmission noise, the equipment in the head office detects those errors and automatically tells the transmitting machine to 'back up and start over'." (Menkhaus, 1967, p. 35).

2.28 "Input interlocks—checks which verify that the correct types and amounts of data have been inserted, in the correct sequence, for each transaction. Such checks can detect many procedural errors committed by persons entering input data into the system." (Hillegass and Melick, 1967, p. 56).

2.29 "Parity—addition of either a 'zero' or 'one' bit to each character code so that the total number of 'one' bits in every transmitted character code will be either odd or even. Character parity checking can detect most single-bit transmission errors, but it will not detect the loss of two bits or of an entire character." (Hillegass and Melick, 1967, p. 56).

"Two of the most popular error detection and correction devices on the market—Tally's System 311 and Digitronics' D500 Series—use retransmission as a correction device. Both transmit blocks of characters and make appropriate checks for valid parity. If the parity generated at the transmitter checks with that which has been created from the received message by the receiver, the transmission continues. If the parity check fails, the last block is retransmitted and checked again for parity. This method avoids the disadvantages of transmitting the entire message twice and of having to compare the second message with the first for validity." (Davenport, 1966, p. 31).

"Full error detection and correction is provided. The telephone line can be severed and reattached hours later without loss of data . . . Error detection is accomplished by a horizontal and vertical parity bit scheme similar to that employed on magnetic tape." (Lynch, 1966, p. 119).

"A technique that has proven highly successful is to group the eight-level characters into blocks of eighty-four characters. One of the eighty-four characters represents a parity character, assuring that the summation of each of the 84 bits at each of eight levels is either always odd or always even. For the block, there is now a vertical parity check (the character parity) and a horizontal parity check (the block parity character). This dual parity check will be invalidated only when an even number of characters within the block have an even number of hits, each at the same level. The probability of such an occurrence is so minute that we can state that the probability of an undetected error is negligible. In an 84-character block, constituting 672 bits, 83+8=91 bits are redundant. Thus, at the expense of adding redundancy of 13.5 per cent, we have assured error-free transmission. At least we know that we can detect errors with certainty. Now, let us see how we can utilize this knowledge to provide error-free data at high transmission rates. One of the most straightforward techniques is to transmit data in blocks, automatically checking each block for horizontal and vertical parity at the receiving terminal. If the block parities check, the receiving terminal delivers the block and an acknowledgment character (ACK) is automatically transmitted back to the sending terminal. This releases the next block and the procedure is repeated. If the block parities do not check, the receiving terminal discards the block and a nonacknowledgment character (NACK) is returned to the sender. Then, the same block is retransmitted. This procedure requires that storage capacity for a minimum of one data block be provided at both sending and receiving terminals." (Rider, 1967, p. 134).

2.30 "What then can we say that will summarize the position of the check digit? We can say that it is useful for control fields—that is, those fields we access by and sort on, customer number, employee number, etc. We can go further and say that it really matters only with certain control fields, not all. With control fields, the keys by which we find and access records, it is essential that they be correct if we are to find the correct record. If they are incorrect through juxtaposition or other errors in transcription, we will 1) not find the record, and 2) find and process the wrong record. . . .

"One of the most novel uses of the check digit can be seen in the IBM 1287 optical scanner. The writer enters his control field followed by the check digit. If one of his characters is not clear, the machine looks at the check digit, carries out its arithmetic on the legible characters, and subtracts the result from the result that would give the check digit to establish the character in doubt. It then rebuilds this character." (Rothery, 1967, p. 59.)

2.31 "A hash total works in the following way. Most of our larger computers can consider alphabetic information as data. These data are added up, just as if they were numeric information, and a meaningless total produced. Since the high-speed electronics are very reliable, they should produce the same meaningless number every time the same data fields are summed. The transfer of information within the computer and to and from the various input/output units can be checked by recomputing this sum after every transmission and checking against the previous total. . . .

"Some computers have special instructions built into them to facilitate this check, whereas others accomplish it through programming. The file designer considers the hash total as a form of built-in audit. Whenever the file is updated, the hash totals are also updated. Whenever a tape is read, the totals are reconstituted as an error check. Whenever an error is found, the operation is repeated to determine if a random error has occurred. If the information is erroneous, an alarm is sounded and machine repair is scheduled. If information has been actually lost, then human assistance is usually required to reconstitute the file to its correct content. Through a combination of hardware and programming the validity of large reference files can be maintained even though the file is subject to repeated usage." (Patrick and Black, 1964, pp. 46–47).

2.32 "Message length—checks which involve a comparison of the number of characters as specified for that particular type of transaction. Message length checks can detect many errors arising from both improper data entry and equipment or line malfunctions." (Hillegass and Milick, 1967, p. 56).

2.33 "In general, many standard techniques such as check digits, hash totals, and format checks can be used to verify correct input and transmission. These checks are performed at the computer site. The nature and extent of the checks will depend on the capabilities of the computer associated with the response unit. One effective technique is to have the unit respond with a verbal repetition of the input data." (Melick, 1966, p. 60).

2.34 "Philco has a contract for building what is called a Spelling-Corrector . . . It reads text and matches it against the dictionary to find out whether the words are spelled correctly." (Gibbs and MacPhail, 1964, p. 102).

"Following keypunching, the information retrieval technician processes the data using a 1401 computer. The computer performs sequence checking, editing, autoproofing (each word of input is checked against a master list of correctly spelled words to determine accuracy—a mismatch is printed out for human analysis since it is either a misspelled or a new word), and checking for illegitimate characters. The data is now on tape; any necessary correction changes or updating can be made directly." (Magnino, 1965, p. 204).

"Prior to constructing the name file, a 'legitimate name' list and a 'common error' name list are tabulated . . . The latter list is formed by taking character error information compiled by the instrumentation system and thresholding it so only errors with significant probabilities remain; i.e., 'e' for 'a'. These are then substituted one character at a time in the names of the 'legitimate name' list to create a 'common error' name list. Knowing the probability of error and the frequency of occurrence of the 'legitimate name' permits the frequency of occurrence for the 'common error' name to be calculated." (Hennis, 1967, pp. 12–13).

2.35 "When a character recognition device errs in the course of reading meaningful English words it will usually result in a letter sequence that is itself not a valid word; i.e., a 'misspelling'," (Cornew, 1968, p. 79).

2.36 "Several possibilities exist for using the information the additional constraints provide. A particularly obvious one is to use special purpose dictionaries, one for physics texts, one for chemistry, one for novels, etc., with appropriate word lists and probabilities in each. . . ."

"Because of the tremendous amount of storage which would be required by such a 'word digram' method, an alternative might be to associate with each word its one or more parts of speech, and make use of conditional probabilities for the transition from one part of speech to another." (Vossler and Branston, 1964, p. D2.4–7).

2.37 "In determining whether or not to adopt an EDC system, the costliness and consequences of any error must be weighed against the cost of installing the error detection system. For example, in a simple telegram or teleprinter message, in which all the information appears in word form, an error in one or two letters usually does not prevent a reader from understanding the message. With training, the human mind can become an effective error detection and correction system; it can readily identify the letter in error and make corrections. Of course, the more unrelated the content of the message, the more difficult it is to detect a random mistake. In a list of unrelated numbers, for example, it is almost impossible to tell if one is incorrect." (Gentle, 1965, p. 70).

2.38 In addition to examples cited in a previous report in this series, we note the following:

"In the scheme used by McElwain and Evens, undisturbed digrams or trigrams in the garbled message were used to locate a list of candidate words each containing the digram or trigram. These were then matched against the garbled sequence taking into account various possible errors, such as a missing or extra dash, which might have occurred in Morse Code transmission." (Vossler and Branston, 1964, p. D2.4–1).

"Harmon, in addition to using digram frequencies to detect errors, made use of a confusion matrix to determine the probabilities of various letter substitutions as an aid to correcting these errors." (Vossler and Branston, 1964, pp. D2.4–1 – D2.4–2).

"An interesting program written by McElwain and Evens was able to correct about 70% of the garbles in a message transmitted by Morse Code, when the received message contained garbling in 0–10% of the characters." (Vossler and Branston, 1964, p. D2.4–1).

"The design of the spoken speech output modality for the reading machine of the Cognitive Information Processing Group already calls for a large, disc-stored dictionary . . . The possibility of a dual use of this dictionary for both correct spelling and correct pronunciation prompted this study." (Cornew, 1968, p. 79).

"Our technique was first evaluated by a test performed on the 1000 most frequent words of English which, by usage, comprise 78% of the written language . . . For this, a computer program was written which first introduced into each of these words one randomly-selected, randomly-placed letter substitution error, then applied this technique to correct it. This resulted in the following overall statistics 739 correct recoveries of the original word prior to any other; 241 incorrect recoveries in which another word appeared sooner; 20 cases where the misspelling created another valid word." (Cornew, 1968, p. 83).

"In operation, the word consisting of all first choice characters is looked up. If found, it is assumed correct; if not, the second choice characters are substituted one at a time until a matching word is found in the dictionary or until all second choice substitutions have been tried. In the latter case a multiple error has occurred (or the word read correctly is not in the dictionary)." (Andrews, 1962, p. 302).

2.39 "There are a number of different techniques for handling spelling problems having to do with names in general and names that are homonyms. Present solutions to the handling of name files are far from perfect." (Rothman, 1966, p. 13).

2.40 "The chief problem associated with . . . large name files rests with the misspelling or misunderstanding of names at time of input and with possible variations in spelling at the time of search. In order to overcome such difficulties, various coding systems have been devised to permit filing and searching of large groups of names phonetically as well as alphabetically . . . A Remington Rand Univac computer program capable of performing the phonetic coding of input names has been prepared." (Becker and Hayes, 1963, p. 143).

"A particular technique used in the MGH [Massachusetts General Hospital] system is probably worth mentioning; this is the technique for phonetic indexing reported by Bolt et al. The use described involves recognition of drug names that have been typed in, more or less phonetically, by doctors or nurses; in the longer view this one aspect of a large effort that must be expended to free the man-machine interface from the need for letter-perfect information representation by the man. People just don't work that way, and systems must be developed that can tolerate normal human imprecision without disaster." (Mills, 1967, p. 243).

2.41 ". . . The object of the study is to determine if we can replace garbled characters in names. The basic plan was to develop the empirical frequency of occurrence of sets of characteres in names and use these statistics to replace a missing character." (Carlson, 1966, p. 189).

"The specific effect on error reduction is impressive. If a scanner gives a 5% character error rate, the trigram replacement technique can correct approximately 95% of these errors. The remaining error is thus . . . 0.25% overall. . . .

"A technique like this may, indeed, reduce the cost of verifying the mass of data input coming from scanners . . . [and] reduce the cost of verifying massive data conversion coming from conventional data input devices like keyboards, remote terminals, etc." (Carlson, 1966, p. 191.)

2.42 "The rules established for coding structures are integrated in the program so that the computer is able to take a fairly sophisticated look at the chemist's coding and the keypunch operator's work. It will not allow any atom to have too many or too few bonds, nor is a '7' bond code permissible with atoms for which ionic bonds are not 'legal'. Improper atom and bond codes and misplaced characters are recognized by the computer, as are various other types of errors." (Waldo and DeBacker, 1959, p. 720).

2.43 "Extensive automatic verification of the file data was achieved by a variety of techniques. As an example, extracts were made of principal lines plus the sequence number of the record: specifically, all corporate name lines were extracted and sorted; any variations on a given name were altered to conform to the standard. Similarly, all law firm citations were checked against each other. All city-and-state fields are uniform. A zip-code-and-place-name abstract was made, with the resultant file being sorted by zip code: errors were easy to sort and correct, as with Des Moines appearing in the Philadelphia listing." (North, 1968, p. 110).

Then there is the even more sophisticated case where ". . . An important input characteristic is that the data is not entirely developed for processing or retrieval purposes. It is thus necessary first to standardize and develop the data before manipulating it. Thus, to mention one descriptor, 'location', the desired machine input might be 'coordinate', 'city', and 'state', if a city is mentioned; and 'state' alone when no city is noted. However, inputs to the system might contain a coordinate and city without mention of a state. It is therefore necessary to develop the data and standardize before further processing commences.

"It is then possible to process the data against the existing file information . . . The objective of the processing is to categorize the information with respect to all other information within the files . . . To categorize the information, a substantial amount of retrieval and association of data is often required . . . Many [data] contradictions are resolvable by the system." (Gurk and Minker, 1961, pp. 263–264).

2.44 "A number of new developments are based on the need for serving clustered environments. A *cluster* is defined as a geographic area of about three miles in diameter. The basic concept is that within a cluster of stations and computers, it is possible to provide communication capabilities at low cost. Further, it is possible to provide communication paths between clusters, as well as inputs to and outputs from other arrangements as optional features, and still maintain economies within each cluster. This leads to a very adaptable system. It is expected to find wide application on university campuses, in hospitals, within industrial complexes, etc." (Simms, 1968, p. 23).

2.45 "Among the key findings are the following:

- Relative cost-effectiveness between time-sharing and batch processing is very sensitive to and varies widely with the precise man-machine conditions under which experimental comparisons are made.
- Time-sharing shows a tendency toward fewer man-hours and more computer time for experimental tasks than batch processing.
- The controversy is showing signs of narrowing down to a competition between conversationally interactive time-sharing versus fast-turnaround batch systems.
- Individual differences in user performance are generally much larger and are probably more economically important than time-sharing/batch-processing system differences.
- Users consistently and increasingly prefer interactive time-sharing or fast turnaround batch over conventional batch systems.
- Very little is known about individual performance differences, user learning, and human decision-making, the key elements underlying the general behavioral dynamics of man-computer communication.
- Virtually no normative data are available on data-processing problems and tasks, nor on empirical use of computer languages and system support facilities—the kind of data necessary to permit representative sampling of problems, facilities and subjects for crucial experiments that warrant generalizable results." (Sackman, 1968, p. 350).

However, on at least some occasions, some clients of a multiple-access, time-shared system may be satisfied with, or actually prefer, operation in a batch or job-shop mode to extensive use of the conversational mode.

"Critics (see Patrick 1963, Emerson 1965, and MacDonald 1965) claim that the efficiency of time-sharing systems is questionable when compared to modern closed-shop methods, or with economical small computers." (Sackman et al., 1968, p. 4).

Schatzoff et al. (1967) report on experimental comparisons of time-sharing operations (specifically, MIT's CTSS system) with batch processing as employed on IBM's IBSYS system.

". . . One must consider the total spectrum of tasks to which a system will be applied, and their relative importance to the total computing load." (Orchard-Hays, 1965, p. 239).

". . . A major factor to be considered in the design of an operating system is the expected job mix." (Morris et al., 1967, p. 74).

"In practice, a multiple system may contain both types of operation: a group of processors fed from a single queue, and many queues differentiated by the type of request being serviced by the attached processor group . . ." (Scherr, 1965, p. 17).

2.46 "Normalization is a necessary preface to the merge or integration of our data. By merge, or integration, as I use the term here to represent the last stage in our processes, I am referring to a complex interfiling of segments of our data—the entries. In this 'interfiling,' we produce, for each article or book in our file, an entry which is a composite of information from our various sources. If one of our sources omits the name of the publisher of a book, but another gives it, the final entry will contain the publisher's name. If one source gives the volume of a journal in which an article appears, but not the month, and another gives the month, but not the volume, our final entry will contain both volume and month. And so on." (Sawin, 1965, p. 95).

"Normalize. Each individual printed source, which has been copied letter by letter, has features of typographical format and style, some of which are of no significance, others of which are the means by which a person consulting the work distinguishes the several 'elements' of the item. The family of programs for normalizing the several files of data will insert appropriate information separators to distinguish and identify the elements of each item and rearrange it according to a selected canonical style, which for the Pilot Study is one which conforms generally to that of the Modern Language Association." (Crosby, 1965, p. 43).

2.47 "Some degree of standardized processing and communication is at the heart of any information system, whether the system is the basis for mounting a major military effort, retrieving documents from a central library, updating the clerical and accounting records in a bank, assigning airline reservations, or maintaining a logistic inventory. There are two reasons for this. First, all information systems are formal schemes for handling the informational aspects of a formally specified venture. Second, the job to be done always lies embedded within some formal organizational structure." (Bennett, 1964, p. 98).

"Formal organizing protocol exists relatively independently of an organization's purposes, origins, or methods. These established operating procedures of an organization impose constraints upon the available range of alternatives for individual behavior. In addition to such constraints upon the degrees of freedon within an organization as restrictions upon mode of dress, conduct, range of mobility, and style of performance, there are protocol constraints upon the format, mode, pattern, and sequence of information processing and information flow. It is this orderly constraint upon information processing and information flow that we call, for simplicity, the information system of an organization. The term 'system' implies little more than procedural restriction and orderliness. By 'information processing' we mean some actual change in the nature of data or documents. By 'information flow' we indicate a similar change in the location of these data or documents. Thus we may define an information system as simply that set of constraining specifications for the collection, storage, reduction, alteration, transfer, and display of organizational facts, opinions, and associated documentation which is established in order to manage, command if you will, and control the ultimate performance of an organization. . . .

"With this in mind, it is possible to recognize the dangers associated with prematurely standardizing the information processing tools, the forms, the data codes, the message layouts, the procedures for message sequencing, the file structures, the calculations, and especially the data-summary forms essential for automation. Standardization of these details of a system is relatively simple and can be accomplished by almost anyone familiar with the design of automatic procedures. However, if the precise nature of the job and its organizational implications are not understood in detail, it is not possible to know the exact influence that these standards will have on the performance of the system." (Bennett, 1964, pp. 99, 103).

2.48 "There is a need for design verification. That is, it is necessary to have some method for ensuring that the design is under control and that the nature of the resulting system can be predicted before the end of the design process. In command-and-control systems, the design cycle lasts from two to five years, the design evolving from a simple idea into complex organizations of hardware, software, computer programs, displays, human operations, training, and so forth. At all times during this cycle the design controller must be able to specify the status of the design, the impact that changes in the design will have on the command, and the probability that certain components of the system will work. Design verification is the process that gives the designer this control. The methods that make up the design-verification process range from analysis and simulation on paper to full-scale system testing." (Jacobs, 1964, p. 44).

2.49 "Measurement of the system was a major area which was not initially recognized. It was necessary to develop the tools to gather data and introduce program changes to generate counts and parameters of importance. Future systems designers should give this area more attention in the design phase to permit more efficient data collection." (Evans, 1967, p. 83.)

2.50 "[The user] is given several control statistics which tell him the amount of dispersion in each category, the amount of overlap of each category with every other category, and the discriminating power of the variables . . . These statistics are based on the sample of documents that he assigns to each category . . . Various users of an identical set of documents can thus derive their own structure of subjects from their individual points of view." (Williams, 1965, p. 219).

2.51 "We will probably see a trend toward the concept of a computer as a collection of memories, buses and processors with distributed control of their assignments on a dynamic basis." (Clippinger, 1965, p. 209).

"Both Dr. Gilbert C. McCann of Cal. Tech and Dr. Edward E. David, Jr., of Bell Telephone Laboratories stressed the need for hierarchies of computers interconnected in large systems to perform the many tasks of a time-sharing system." (Commun. ACM **9**, 645 (Aug. 1966).)

2.52 "Every part of the system should consist of a pool of functionally identical units (memories, processors and so on) that can operate independently and can be used interchangeably or simultaneously at all times . . .

"Moreover, the availability of duplicate units would simplify the problem of queuing and the allocation of time and space to users." (Fano and Corbató, 1966, pp. 134–135).

"Time-sharing demands high system reliability and maintainability, encourages redundant, modular, system design, and emphasizes high-volume storage (both core and auxiliary) with highly parallel system operation." (Gallenson and Weissman, 1965, p. 14).

"A properly organized multiple processor system provides great reliability (and the prospect of continuous operation) since a processor may be trivially added to or removed from the system. A processor undergoing repair or preventive maintenance merely lowers the capacity of the system, rather than rendering the system useless." (Saltzer, 1966, p. 2).

"Greater modularity of the systems will mean easier, quicker diagnosis and replacement of faulty parts." (Pyke, 1967, p. 162).

"To meet the requirements of flexibility of capacity and of reliability, the most natural form . . . is as a modular multiprocessor system arranged so that processors, memory modules and file storage units may be added, removed or replaced in accordance with changing requirements." (Dennis and Van Horn, 1965, p. 4). See also notes 5.83, 5.84.

2.53 "The actual execution of data movement commands should be asynchronous with the main processing operation. It should be an excellent use of parallel processing capability." (Opler, 1965, p. 276).

2.54 "Work currently in progress [at Western Data Processing Center, UCLA] includes: investigations of intra-job parallel processing which will attempt to produce quantititative evaluations of component utilization; the increase in complexity of the task of programming; and the feasibility of compilers which perform the analysis necessary to convert sequential programs into parallel-path programs." (Dig. Computer Newsletter **16**, No. 4, 21 (1964).)

2.55 "The motivation for encouraging the use of parallelism in a computation is not so much to make a particular computation run more efficiently as it is to relax constraints on the order in which parts of a computation are carried out. A multi-program scheduling algorithm should then be able to take advantage of this extra freedom to allocate system resources with greater efficiency." (Dennis and Van Horn, 1965, pp. 19–20).

2.56 Amdahl remarks that "the principal motivations for multiplicity of components functioning in an on-line system are to provide increased capacity or increased availability or both." (1965, p. 38). He notes further that "by pooling, the number of components provided need not be large enough to accommodate peak requirements occurring concurrently in each computer, but may instead accommodate a peak in one occurring at the same time as an average requirement in the other." (Amdahl, 1965, pp. 38–39).

2.57 "No large system is a static entity—it must be capable of expansion of capacity and alteration of function to meet new and unforeseen requirements." (Dennis and Glaser, 1965, p. 5).

"Changing objectives, increased demands for use, added functions, improved algorithms and new technologies all call for flexible evolution of the system, both as a configuration of equipment and as a collection of programs." (Dennis and Van Horn, 1965, p. 4).

"A design problem of a slightly different character, but one that deserves considerable emphasis, is the development of a system that is 'open-ended'; i.e., one that is capable of expansion to handle new plants or offices, higher volumes of traffic, new applications, and other difficult-to-foresee developments associated with the growth of the business. The design and implementation of a data communications system is a major investment; proper planning at design time to provide for future growth will safeguard this investment." (Reagan, 1966, p. 24).

2.58 "Reconfiguration is used for two prime purposes: to remove a unit from the system for service or because of malfunction, or to reconfigure the system either because of the malfunction of one of the units or to 'partition' the system so as to have two or more independent systems. In this last case, partitioning would be used either to debug a new system supervisor or perhaps to aid in the diagnostic analysis of a hardware malfunction where more than a single system component were needed." (Glaser et al., 1965, p. 202.)

"Often, failure of a portion of the system to provide services can entail serious consequences to the system users. Thus severe reliability standards are placed on the system hardware. Many of these systems must be capable of providing service to a range in the number of users and must be able to grow as the system finds more users. Thus, one finds the need for modularity to meet these demands. Finally, as these systems are used, they must be capable of change so that they can be adapted to the ever changing and wide variety of requirements, problems, formats, codes and other characteristics of their users. As a result general-purpose stored program computers should be used wherever possible." (Cohler and Rubenstein, 1964, p. 175).

2.59 "On-line systems are still in their early development stage, but now that systems are beginning to work, I think that it is obvious that more attention should be paid to the fail safe aspects of the problem." (Huskey, 1965, p. 141).

"From our experience we have concluded that system reliability . . . must provide for several levels of failure leading to the term 'fail-soft' rather than 'fail-safe'." (Baruch, 1967, p. 147).

Related terms are "graceful degradation" and "high availability", as follows:

"The military is becoming increasingly interested in multiprocessors organized to exhibit the property of *graceful degradation*. This means that when one of them fails, the others can recognize this and pick up the work load of the one that failed, continuing this process until all of them have failed." (Clippinger, 1965, p. 210).

"The term 'high availability' (like its synonym 'fail safe') has now become a cliche, and lacks any precise meaning. It connotes a system characteristic which permits recovery from all hardware errors. Specifically, it appears to promise that critical system and user data will not be destroyed, that system and job restarts will be minimized and that critical jobs can most surely be executed, despite failing hardware. If this is so, then multiprocessing per se aids in only one of the three characteristics of high availability." (Witt, 1968, p. 699).

"The structure of a multi-computer system planned for high availability is principally determined by the permissible reconfiguration time and the ability to fail safely or softly. The multiplicity and modularity of system components should be chosen to provide the most economical realization of these requirements . . .

"A multi-computer system which can perform the full set of tasks in the presence of a single malfunction is fail-safe. Such a system requires at least one more unit of each type of system component, with the interconnection circuitry to permit it to replace any of its type in any configuration . . .

"A multi-computer system which can perform a satisfactory subset of its tasks in the presence of a malfunction is fail-soft. The set of tasks which must still be performed to provide a satisfactory through degraded level of operation, determines the minimum number of each component required after a failure of one of its type." (Amdahl, 1965, p. 39).

"Systems are designed to provide either full service or graceful degradation in the face of failures that would normally cause operations to cease. A standby computer, extra mass storage devices, auxiliary power sources to protect against public utility failure, and extra peripherals and communication lines are sometimes used. Manual or automatic switching of spare peripherals between processors may also be provided." (Bonn, 1966, p. 1865).

2.60 "A third main feature of the communication system being described is high reliability. The emphasis here is not just on dependable hardware but on techniques to preserve the integrity of the data as it moves from entry device, through the temporary storage and data modes, over the transmission lines and eventually to computer tape or hard copy printer." (Hickey, 1966, p. 181.)

2.61 In addition to the examples cited in the discussion of client and system protection in the previous report in this series (on processing, storage, and output requirements, Section 2.2.4), we note the following:

"The primary objective of an evolving special-purpose time-sharing system is to provide a real service for people who are generally not computer programmers and furthermore depend on the system to perform their duties. Therefore the biggest operational problem is reliability. Because the data attached to special-purpose system are important and also must be maintained for a long time, reliability is doubly crucial, since errors affecting the data base cannot only interrupt users' current procedures but also jeopardize past work." (Castleman, 1967, p. 17).

"If the system is designed to handle both special-purpose functions and programming development, then why is reliability a problem? It is a problem because in a real operating environment some new 'dangerous' programs cannot be tested on the system at the same time that service is in effect. As a result, new software must be checked out during offhours, with two consequences. First, the system is not subjected to its usual daytime load during checkout time. It is a characteristic of time-shared programs that different 'bugs' may appear depending on the conditions of the overall system activity. For example, the 'time-sharing bug' of a program manipulating data incorrectly because another program processes the same data at virtually the same time would be unlikely on a lightly loaded system. Second, programmers must simulate at night their counterparts of laymen users. Unfortunately, these two types of people tend to use application programs differently and to make different types of errors; so program debugging is again limited. Therefore, because the same system is used for both service and development, programs checked as rigorously as possible can still cause system failures when they are installed during actual service hours." (Castleman, 1967, p. 17).

"Protection of a disk system requires that no user be able to modify the system, purposely or inadvertently, thus preserving the integrity of the software. Also, a user must not be able to gain access to, or modify any other user's program or data. Protection in tape systems is accomplished: (1) by making the tape units holding the system records inaccessible to the user, (2) by making the input and output streams one-way (e.g., the input file cannot be backspaced), and (3) by placing a mark in the input stream which only the system can cross. In order to accomplish this, rather elaborate schemes have been devised both in hardware and software to prevent the user from accomplishing certain input-output manipulations. For example, in some hardware, unauthorized attempts at I/O manipulation will interrupt the computer.

"In disk-based systems, comparable protection devices must be employed. Since many different kinds of records (e.g., system input, user scratch area, translators, etc.) can exist in the same physical disk file, integrity protection requires that certain tracks, and not tape units, must be removed from the realm of user access and control. This is usually accomplished by partitioning schemes and central I/O software systems similar to those used in tape-based systems. The designer must be careful to preserve flexibility while guaranteeing protection." (Rosin, 1966, p. 242).

2.62 "Duplex computers are specified with the spare and active computers sharing I/O devices and key data in storage, so that the spare computer can take over the job on demand." (Aron, 1967, p. 54).

"The second channel operates in parallel with the main channel, and the results of the two channels are compared. Both channels must independently arrive at the same answer or operation cannot proceed. The duplication philosophy provides for two independent access arms on the Disk Storage Unit, two core buffers, and redundant power supplies." (Bowers et al., 1962, p. 109).

"Considerable effort has been continuously directed toward practical use of massive triple modular redundancy (TMR) in which logic signals are handled in three identical channels and faults are masked by vote-taking elements distributed throughout the system." (Avižienis, 1967, p. 735).

"He must give consideration to 1) back-up power supplies that include the communications gear, 2) dual or split communication cables into his data center, 3) protection of the center and its gear from fire and other hazards, 4) insist that separate facilities via separate routes and used to connect locations on the MIS network, and 5) build extra capacity into the MIS hardware system." (Dantine, 1966, p. 409).

"It is far better to have the system running at half speed 5% of the time with no 100% failures than to have the system down 2½% of the time." (Dantine, 1966, p. 409).

"Whenever possible, the two systems run in parallel under the supervision of the automatic recovery program. The operational system performs all required functions and monitors the back-up system. The back-up system constantly repeats a series of diagnostic tests on the computer, memory and other modules available to it and monitors the operational system. These tests are designed to maintain a high level of confidence in these modules so that should a respective counterpart in the operational system fail, the back-up unit can be safely substituted. The back-up system also has the capability of receiving instructions to perform tests on any of its elements and to execute these tests while continuing to monitor the operational system to confirm that the operational system has not hung up." (Armstrong et al., 1967, p. 409).

2.63 "The large number of papers on vote-taking redundancy can be traced back to the fundamental paper of Von Neuman where multiple-line redundancy was first established as a mathematical reality for the provision of arbitrarily reliable systems" (Short, 1968, p. 4).

2.64 "A computer system contains protective redundancy if faults can be tolerated because of the use of additional components or programs, or the use of more time for the computational tasks. . . .

"In the massive (masking) redundancy approach the effect of a faulty component, circuit, signal, subsystem, or system is masked instantaneously by permanently connected and concurrently operating replicas of the faulty element. The level at which replication occurs ranges from individual circuit components to entire self-contained systems." (Avižienis, 1967, p. 733–734).

2.65 "An increase in the reliability of systems is frequently obtained in the conventional manner by replicating the important parts several (usually three) times, and a majority vote . . . A technique of diagnosis performed by nonbinary matrices . . . require, for the same effect, only one duplicated part. This effect is achieved by connecting the described circuit in a periodically changing way to the duplicated part. If one part is disturbed the circuit gives an alarm, localizes the failure and simultaneously switches to the remaining part, so that a fast repair under operating conditions (and without additional measuring instruments) is possible." (Steinbuch and Piske, 1963, p. 859).

2.66 "Parameters of the model are as follows:

n = total number of modules in the system
m = number of unfailed modules needed for system survival
Pf = Probability of failure of each module some time during the mission. This parameter thus includes both the mission duration and the module MTBF.
Pnd = probability of not detecting an occurred module failure
PS = probability of system survival throughout the mission
$P_f = 1 - PS$ = probability of system failure during the mission
n/m = redundancy factor in initial system. . . .

"Depending upon the attainable P_f and P_{nd}, the theoretical reliability of a multi-module computing system may be degraded by adding more than a minimal amount of redundancy. For example, $P_f = 0.025$ . . . it is more reliable to have only one spare module rather than two or four, for a typical current-day P_{nd} such as 0.075. Even for a P_{nd} as low as 0.03 (a very difficult P_{nd} to achieve in a computer), the improvement obtained in system reliability by adding a second spare unit to the system is minor." (Wyle and Burnett, 1967, pp. 746, 748).

"The probability of system failure . . . is:

$$P_F = \sum_{k=(n-m+1)}^{k=n} \frac{n!}{(n-k)!k!} (P_f)^k (1-P_f)^{n-k}$$

$$+ \sum_{k=1}^{k=(n-m)} \frac{n!}{(n-k!)k!} P_f^k (1-P_f)^{n-k} [1-(1-P_{nd})^K].$$

(Wyle and Burnett, 1967, p. 746).

2.67 "One of the system design considerations is the determination of the optimum number of redundant units by means of which the required system reliability is to be reached. It will be seen that P_{nd} as well as P_f must be considered in determining the most economical design." (Wyle and Burnett, 1967, p. 748).

"One of the prime requisites for a reliable, dependable communications data processing system is that it employ features for insuring message protection and for knowing the disposition of every message in the system (message accountability) in case of equipment failures. The degree of message protection and accountability will vary from application to application." (Probst, 1968, p. 21).

"Elaborate measures are called for to guarantee message protection. At any given moment, a switching center may be in the middle of processing many different messages in both directions. If a malfunction occurs in any storage or processing device, there must be enough information stored elsewhere in the center to analyze the situation, and to repeat whatever steps are necessary. This means that any item of information must be stored in at least two independent places, and that the updating of queue tables and other auxiliary data must be carefully synchronized so that operation can continue smoothly after correction of a malfunction. If it cannot be determined exactly where a transmission was interrupted, procedures should lean toward pessimism. Repetition of a part of a message is less grievous than a loss of part of it." (Shafritz, 1964, p. N2.3–3).

"Reference copies are kept on magnetic tapes for protective accountability of each message. Random requests for retransmission are met by a computer search of the tape, withdrawal of the required messages and automatic reintroduction of the message into the communications system." (Jacobellis, 1964, p. N2.1–2).

"Every evening, the complete disc file inventory is pruned and saved on tape to be reloaded the following day. This gives a 24-hour 'rollback' capability for catastrophic disc failures." (Schwartz and Weissman, 1967, p. 267).

"It is necessary to provide means whereby the contents of the disc can be reinstated after they have been damaged by system failure. The most straightforward way of doing this is for the disc to be copied on to magnetic tape once or twice a day; re-writing the disc then puts the clock back, but users at least know where they are. Unfortunately, the copying of a large disc consumes a lot of computer time, and it seems essential to develop methods whereby files are copied on to magnetic tape only when they are created or modified. It would be nice to be able to consider the archive and recovery problems as independent, but reasons of efficiency demand that an attempt should be made to develop a satisfactory common system. We have, unfortunately, little experience in this area as yet, and are still groping our way." (Wilkes, 1967, p. 7).

"Our requirements, therefore, were threefold: security, retrieval, and storage. We investigated various means by which we could meet these requirements; and we decided on the use of microfilm, for two reasons. First, photographic copies of records, including those on microfilm, are acceptable as legal representations of documents. We could photograph our notebooks, store the film in a safe place, and destroy the books or, at least, move them to a larger storage area. Second, we found on the market equipment with which we could film the books and then, with a suitable indexing system, obtain quick retrieval of information from that film" (Murrill, 1966, p. 52).

"The file system is designed with the presumption that there will be mishaps, so that an automatic file backup mechanism is provided. The backup procedures must be prepared for contingencies ranging from a dropped bit on a magnetic tape to a fire in the computer room.

"Specifically, the following contingencies are provided for:

"1. A user may discover that he has accidentally deleted a recent file and may wish to recover it.

"2. There may be a specific system mishap which causes a particular file to be no longer readable for some 'inexplicable' reason.

"3. There may be a total mishap. For example, the disk-memory read heads may irreversibly score the magnetic surfaces so that all disk-stored information is destroyed.

"The general backup mechanism is provided by the system rather than the individual user, for the more reliable the system becomes, the more the user is unable to justify the overhead (or bother) of trying to arrange for the unlikely contingency of a mishap. Thus an individual user needs insurance, and, in fact, this is what is provided." (Corbatò and Vyssotsky, 1965, p. 193).

"Program roll-back for corrective action must be routine or function oriented since it is impractical from a storage requirement point of view to provide corrective action for each instruction. The roll-back must be to a point where initial conditions are available from sensors, prestored, or reconstitutable. Even an intermittent memory malfunction during access becomes a persistent error since it is immediately rewritten in error. Thus, critical routines or high iteration rate real-time routines (for example, those which perform integration with respect to time) should be stored redundantly so that in the event of malfunction the redundantly stored routine is used to preclude routine malfunction or error buildup with time." (Bujnoski, 1968, p. 33).

2.68 "Restart procedures should be designed into the system from the beginning, and the necessity for the system to spend time in copying vital information from one place to another should be cheerfully accepted. . . .

"Redundant information can be included in supervisor communication or data areas in order to enable errors caused by system failure to be corrected. Even a partial application of this idea could lead to important improvements in restart capability. A system will be judged as much as by the efficiencies of its restart procedures as by the facilities that it provides. . . .

"Making it possible for the system to be restarted after a failure with as little loss as possible should be the constant preoccupation of the software designer." (Wilkes and Needham, 1968, p. 320).

"Procedures must also be prescribed for work with the archive collection to prevent loss or contamination of the master records by tape erasure, statistical adjustment, aggregation or reclassification." (Glaser et al., 1967, p. 19).

2.69 "Standby equipment costs should receive some consideration, particularly in a cold war situation: duplicate tapes, raw data or semi-processed data. Also consider the possible costs of transporting classified data elsewhere for computation: express, courier, messenger, Brink's service." (Bush, 1956, p. 110).

"For companies in the middle range, the commercial underground vaults offer excellent facilities at low cost. Installations of this type are available in a number of states, including New York, Pennsylvania, Kansas, Missouri and California. In addition to maximum security, they provide pre-attack clerical services and post-attack conversion facilities. The usual storage charge ranges from $2 to $5 a cubic foot annually, depending on whether community or private storage is desired. . . .

"The instructions should detail procedure for converting each vital record to useable form, as well as for utilizing the converted data to perform the desired emergency functions. The language should be as simple as possible and free of 'shop' terms, since inexperienced personnel will probably use the instructions in the post-attack." (Butler, 1962, pp. 65, 67.)

2.70 "The trend away from supporting records is a recent development that has not yet gained widespread acceptance. There is ample evidence, however, that their use will decline rapidly, if the cold war gets uncomfortably hot. Except for isolated areas in their operations, an increasing number of companies are electing to take a calculated risk in safeguarding basic records but not the supporting changes. For example, some of the insurance companies microfilm the basic in-force policy records annually and forego the changes that occur between duplicating cycles. This is a good business risk for two reasons: (1) supporting records are impractical for most emergency operations, and (2) a maximum one-year lag in the microfilm record would not seriously hamper emergency operations." (Butler, 1962, p. 62.)

"Mass storage devices hold valuable records, and backup is needed in the event of destruction or nonreadability of a record(s). Usually the entire file is copied periodically, and a journal of transactions is kept. If necessary, the file can be reconstructed from an earlier copy plus the journal to date." (Bonn, 1966, p. 1865).

2.71 "The life and stability of the [storage] medium under environmental conditions are other considerations to which a great deal of attention must be paid. How long will the medium last? How stable will it be under heat and humidity changes?" (Becker and Hayes, 1963, p. 284).

It must be noted that, in the present state of magnetic tape technology, the average *accurate* life of tape records is a matter of a few months only. The *active* master files are typically rewritten on new tapes regularly, as a part of normal updating and maintenance procedures. Special precautions must be undertaken, however, to assure the same for duplicate master tapes, wherever located.

"Security should also be considered in another sense. Paper must be protected against fire and flooding, magnetic tapes against exposure to electromagnetic fields and related hazards. No special precaution is necessary for microfilm, provided the reels are replaced periodically in updating cycles. Long-term storage of microfilm, however, will require proper temperature and humidity control in the storage area." (Butler, 1962, p. 64.)

3. Problems of System Networking

3.1 As noted in a previous report in this series: "Information processing systems *are* but one facet of an evolving field of intellectual activity called communication sciences. This is a *generic* term which is applied to those areas of study in which the interest centers on the properties of a system or the properties of arrays of symbols which come from their organization or structure rather than from their physical properties; that is, the study of what one M.I.T. colleague calls 'the problems of organized complexity'." (Wiesner, 1958, p. 268).

The terminology apparently originated with Warren Weaver. Weaver (1948) noted first that the areas typically tackled in scientific research and development efforts up to the twentieth century were largely concerned with two-variable *problems of simplicity;* then from about 1900 on, powerful techniques such as those of probability theory and statistical mechanics were developed to deal with *problems of disorganized complexity* (that is, those in which the number of variables is very large, the individual behavior of each of the many variables is erratic or unknown, but the system as a whole has analyzable average properties). Finally, he points to an intermediate region "which science has as yet little explored or conquered" (1948, p. 539), where by contrast to those disorganized or random situations with which the statistical techniques can cope, the *problems of organized complexity* require dealing simultaneously with a considerable number of variables that are interrelated in accordance with organizational factors.

3.2 "*Organizational generality* is an attribute of underrated importance. The correct functioning of on-line systems imposes requirements that have been met *ad hoc* by current designs. Future system designs must acknowledge the basic nature of the problems and provide general approaches to their resolution." (Dennis and Glaser, 1965, p. 5).

"Diversity of needs and divisibility of computer resources demand a much more sophisticated multiplexing strategy than the simple communication case where all users are treated alike." (David, 1966, p. 40).

"As we turn toward stage three, the stage characterized by the netting of geographically distributed computers, we find ourselves with a significant base of experience with special-purpose computer networks, but with essentially no experience with general-purpose computer networks of the kind that will come into being when multiple-access systems such as those at M.I.T. and the Systems Development Corporation are linked by digital transmission channels. The difficulties involved in establishing computer networks appear not to be difficulties of hardware design or even of hardware availability. Rather, they appear to be difficulties of social and software organization, of conventions, formats, and standards, of programming, interaction, and communication languages. It is a situation in which there now exist all the component hardware facilities that can be said to be required, yet in which there do not now exist any general-purpose networks capable of supporting stage-three interaction." (Licklider, 1967, pp. 5–6).

"The state of affairs at the end of 1966 can be summarized as follows. Multiaccess-system application techniques and user-oriented subsystems have been developed to only a relatively primitive level. Far too many people, particularly those with a scientific-application bent, still hold the short-sighted view that the real value of large, multiaccess systems lies in their ability to simultaneously present a powerful 'private computer' to each of several tens or hundreds of programmers. Nearly all of the systems actually in operation are used in this way. Application-oriented systems that free the user of most, or all, of his concern with details of computer-system characteristics and conventional programming are coming much more slowly. Their development has been inhibited by, among other things, the temporary plateau that has been reached in basic multiaccess system technology." (Mills, 1967, p. 247).

3.3 "The analytical tools are simply not available . . ." (Baran, 1964, p. 27).

"The essence of rational benefit-cost analysis is the tracing of indirect as well as direct effects of programs and the evaluation and summing of these effects. Typically, the methodology for tracing all but the most obvious linkages is entirely lacking or fails to use the relevant information." (Glaser et al., 1967, p. 15).

"The problem associated with providing the interconnection of a network of processors is a major one." (Estrin and Kleinrock, 1967, p. 92).

"Solving the data base management problems of a distributed network has been beyond the state of the art." (Dennis, 1968, p. 373).

"Although techniques for multiplex communications are well developed, we are only beginning to learn how to multiplex computers." (David, 1966, p. 40).

"The formalism of hardware/software system management is just beginning to take shape. SAGE is a landmark because it worked in spite of its immense size and complexity." (Aron, 1967, p. 50).

"The system engineer presently lacks sufficient tools to efficiently design, modify or evaluate complex information systems." (Blunt, 1965, p. 69).

3.4 "The design and analysis problems associated with large communications networks are frequently not solvable by analytic means and it is therefore necessary to turn to simulation techniques. Even with networks which are not particularly large the computational difficulties encountered when other than very restrictive and simple models are to be considered preclude analysis. It has become clear that the study of network characteristics and traffic handling procedures must progress beyond the half-dozen switching center problem to consider networks of dozens of nodes with hundreds or even thousands of trunks so that those features unique to these large networks can be determined and used in the design of communications systems. Here it is evident that simulation is the major study tool." (Weber and Gimpelson, 1964, p. 233).

"The time and costs involved make it almost mandatory to 'prove' the 'workability' and feasibility of the potential solutions via pilot systems or by implementation in organizations or associations which have some of the characteristics of the national system and which would therefore serve as a model or microcosm of the National Macrocosm." (Ebersole, 1966, p. 34).

"A report by Churchill et al., specifically recognizes the need for theoretical research in order to build an adequate foundation on which to base systems analysis procedures. They point out that recent computer developments and particularly large computer systems have increased the need for research and the body of data that research can provide in such areas as data coding and file organization." (Borko, 1967, p. 37).

3.5 "The coming importance of networks of computers creates another source of applications for . . . multiple-queue disciplines. Computer network disciplines will also have to be dependent on transmission delays of service requests and jobs or parts of jobs from one computer to another as well as on the possible incompatibilities of various types between different computers. The synthesis and analysis of multiprocessor and multiple processor network priority disciplines remains a fertile area of research whose development awaits broad multiprocessor application and an enlightening experience with the characteristics of these disciplines." (Coffman and Kleinrock, 1968, p. 20).

"We still are plagued by our inability to program for simultaneous action, even for the scheduling of large units in a computing system." (Gorn, 1966, p. 232).

"As computer time-sharing systems have evolved from a research activity to an operational activity, and have increased in size and complexity, it has become clear that significant problems occur in controlling the use of such systems. These problems have evidenced themselves in computer scheduling, program capability constraints, and the allotment of auxiliary storage." (Linde and Chaney, 1966, p. 149).

"A network has to consider with great care the many possibilities of user access which approach more and more the vast possibilities and intricacies of direct human communication." (Cain and Pizer, 1967, p. 262).

"Increased attention needs to be placed on the problem of techniques for scheduling the many users with their different priorities." (Bauer, 1965, p. 23).

3.6 "Much of the design effort in a message-switching type communications system goes into the network which links the terminals and nodal points together. The distribution of terminals can be shown, the current message density is known, and programs exist to help lay out the network. *With most interactive systems this is not the case.*" (Stephenson, 1968, p. 56).

3.7 "In looking toward computer-based, computer-linked library systems, that have been proposed as a national technical information network, studies of perceived needs among users are likely to be of very little use. Instead it would seem to be more appropriate to initiate small-scale experiments designed to produce, on a limited basis, the effects of a larger-scale system in order to determine whether such experiments produce the expected benefits." (Schon, 1965, p. 34).

3.8 "Transmitting data collection systems can assume a wide variety of equipment configurations, ranging from a single input unit with cable-connected recorded to a farflung network with multiple input units transmitting data to multiple recorders or computers by means of both common-carrier facilities and direct cable connections. Probably the most important parameter in planning the equipment configuration of a system is the maximum number of input stations that can be connected to a single central recording unit." (Hillegass and Melick, 1967, pp. 50–51).

3.9 Licklider stresses the importance of "coherence through networking" and emphasizes: "On the average, each of *n* cooperative users can draw *n–1* programs from the files for each one he puts into the public files. That fact becomes so obviously significant as *n* increases that I can conclude by concluding that the most important factors in software economics are *n*, the number of netted users, and *c*, the coefficient of contributive cooperativeness that measures the value to his colleagues of each user's creative effort." (Licklider, 1967, p. 13).

"The circumstances which appear to call for the establishment of physical networks (as opposed to logical networks) are generally:

"1. The existence of special data banks or special collections of information located at a single institution but useful to an audience geographically dispersed.

"2. The inadequacy of general data banks or general collections of information to meet local needs where remote resources can be used in a complementary fashion to fulfill the need.

"3. The centralization of programming services, processing capabilities or scientific resources with a geographically dispersed need.

"4. The need for interpersonal (including intergroup) direct communication. This includes teleconferencing and educational activities.

"5. A justification on economic, security or social grounds for distribution of responsibility for load sharing among organizations or geographical regions." (Davis, 1968, pp. 1–2).

"In certain areas, such as law enforcement, medicine, social security, and education, there is a need for joint Federal-State computer communications networks which can apply new technology to improving the management of major national programs in these areas." (Johnson, 1967, p. 5).

"It has been suggested that a principal advantage to be gained from computer networks is the ability to distribute work evenly over the available installations or to perform certain computations at installations particularly suited to the nature of the job." (Dennis, 1968, p. 374).

"The time-sharing computer system can unite a group of investigators in a cooperative search for the solution to a common problem, or it can serve as a community pool of knowledge and skill on which anyone can draw according to his needs." (Fano and Corbató, 1966, p. 129).

"Within a computer network, a user of any cooperating installation would have access to programs running at other cooperating installations, even though the programs were written in different languages for different computers. This forms the principal motivation for considering the implementation of a network." (Marill and Roberts, 1966, p. 426).

3.10 "The establishment of a network may lead to a certain amount of specialization among the cooperating installations. If a given installation, X, by reason of special software or hardware, is particularly adept at matrix inversion, for example, one may expect that users at other installations in the network will exploit this capability by inverting their matrices at X in preference to doing so on their own computers." (Marill and Roberts, 1966, p. 426).

"An interconnected network would make it possible for the top specialists in any field to instruct anyone within the reach of a TV receiver." (Brown et al., 1967, p. 74).

3.11 "For initial network trials the advantages of an open system are:

a. ease of programming,
b. services for all users,
c. all operations may be publicized." (Brown et al., 1967, p. 209).

3.12 "The operator's charges to clients must be in fair proportion to the usage made of installation resources (processing, time, storage occupancy, etc.). Therefore adequate records must be kept of resource use." (Dennis, 1968, p. 375).

"A principal [individual or group of individuals] is charged for resources consumed by computations running on his behalf. A principal is also charged for retention in the system of a set of computing entities called *retained objects*, which may be program and data segments . . ." (Dennis and Van Horn, 1965, p. 8).

"The equitable allocation of space and time by administrative fiat. This is probably an overwhelming problem in a network since the predicting of communication paths and computing facilities required by any user would be quite unwieldy. . . .

"Thus a more elaborate scheme seems to be necessary—one whose rates are proportional to the value of the service. This would be modified in a network because the rate for the same kind of service may vary among the installations." (Brown et al., 1967, p. 212).

"Built-in accounting and analysis of system logs are used to provide a history of system performance as well as establish a basis for charging users." (Estrin et al., 1967, p. 645).

3.13 "Questions of technical feasibility and economic value are not the sole determinants of the computer utility. The development of the computer utility may be influenced by norms, or lack of norms, about the confidentiality of data. At the moment there do not seem to be any clear standards of good practice; perhaps there was less need before technology greatly increased capabilities for handling data." (Jones, 1967, p. 555).

"It should be easy and convenient for a user to allow controlled access to any of his segments, with different access privileges for different users." (Graham, 1968, p. 367).

3.14 "The designer must decide whether he will provide the high-speed service to all users, to provide the service that the majority request, and leave the minority to fend for themselves, or to provide the degree of speed needed in each case, but no more. Ideally, he should know the entire distribution of response time requirements. It is even desirable to know how the arrival of these queries will be distributed in time throughout the day. In attempting to meet requirements, he must consider what is actually being retrieved in any stated response interval. Does the user want hard copy or will he be satisfied with citations or index records? The engineering problems associated with high-speed retrieval of hard copy from files can be formidable. If a conversational, or browsing, mode of search is used in which the searcher uses a succession of queries, do we aim to minimize his total search time, or only to give him immediate response to each single query?" (Meadow, 1967, p. 191).

"Precedence is computed as a composite function of:

1) the ability of the network to accept additional traffic;
2) the 'importance' of each user and the 'utility' of his traffic;
3) the data rate of each input transmission medium or the transducer used;
4) the tolerable delay time for delivery of the traffic." (Baran, 1964, p. v).

"Many separate low-data-rate devices time-shared or concentrated into a single high-data-rate link permit better averaging, as compared to a few correspondingly-higher-data-rate users. But, as many of the high-data-rate users 'get in' and 'get out' fast, they have a short holding time. This helps the averaging process. To be precise in this computation, a better understanding of the number of users, their use statistics, and the network characteristics appears mandatory.

". . . The mixed requirement that, while we wish to give priority treatment to the higher-precedence traffic of equal network loading, we must also satisfy the goal that we preserve a minimum transmission capability for the lower-precedence traffic. Thus, instead of a blanket rule that all traffic of a given precedence grade will be transmitted before handling the next lower precedence grade, we choose to use the time ratios of these precedence categories to act as a preference weighting factor." (Baran, 1964, pp. 30, 33).

"An added complication may be introduced in the form of a hierarchy of precedence classifications. This can be a very useful feature of the communications system, allowing important messages to avoid delay by by-passing a string of messages of relatively low urgency. But it adds an extra dimension to the message queue, requiring separate listings for each precedence. This system can go beyond governing of the order of transmission, and can allow high-priority messages to interrupt others during their transmission. In such a system, message switching has an advantage over circuit switching, in that an interrupted message can be automatically retransmitted as soon as possible, with no further action by the sender. But the possibility of interruption necessitates that the entire contents of a message be retained in storage until its last transmission is completed." (Shafritz, 1964, p. N2.3–3).

"The difference between control strength and priority is that control strength is used for defining interrupt classes (an interrupt class is the set of all requests with the same control strength), while priority is used for ordering requests within the same interrupt class." (Dahm et al., 1967, p. 774).

3.15 "In real time data communications oriented problems, four major system equipment performance factors must be evaluated:

1. Real time processing capability of central processor(s)
2. Core memory size provided in central processor(s)
3. Bulk storage size provided
4. Limitations on real time access to bulk storage." (Birmingham, 1964, p. 38.)

3.16 "It seems imperative that EDUCOM . . . establish certain technical standards and operation procedures which each state or regional group must meet before they can be interconnected. These standards should apply to digital transmission, telephonic communications, and television . . ." (Brown et al., 1967, p. 54).

"One final thought about integration. Integration is facilitated by the standardization of equipment, processes, and languages. However, standardization in command-and-control systems must be considered in the light of the evolutionary nature of these systems. First, standardization should be based upon those elements which are mission-independent; that is, the elements standardized should be general-purpose in nature. Secondly, the standardization of system elements should be modular; that is, it should be possible to add other elements to them in order to modify or increase the capabilities of the system. If system elements are standardized at too low a level of aggregation, the system's speed of response is increased, but its flexibility is reduced. If, on the other hand, elements are standardized at the higher levels of aggregation, provided these are not higher than the level of the designer's problem, flexibility is increased, but there is an accompanying reduction in the system's speed of response. It is this trade-off between flexibility and speed of response that makes the standardization problem such a difficult one." (Jacobs, 1964, pp. 41–42).

"In general the standards of distributed-control systems are standards built around each class of job for each level of job for each unique function of the system. Procedures and languages need not be standardized across job levels or across functions. Minimum standardization does not, however, imply the complete freedom of each functional unit to select idiosyncratic communication codes or bizarre formats. Such matters as codes, formats, file structures, vocabularies, and message syntax are all aspects of performance programs, and the library of these program building blocks, from which any information-processing job can be built, is bounded from above. Executive control over the limits of the library establishes the boundaries of the range of alternatives available at any organizational level. This is standardization of a sort, but it allows considerably more flexibility than the standardization generated by a rigid set of specifications to be applied across functions and up and down the hierarchy of information-processing jobs." (Bennett, 1964, p. 107).

3.17 "A built-in system for user feedback would be essential in determining near-future needs and current inadequacies of the network." (Brown et al., 1967, p. 216).

"It was considered that it might be useful to have all users of materials feed back their evaluations, which could be analyzed statistically for consideration of the next user." (Brown et al., 1967, p. 63).

"Provisionally we characterize a network by:

A. Remote and rapid services regarding selection, acquisition, organization, storage, retrieval, and processing of information and procedures in current files . . .
B. Feedback to the
    1. Originator or organizer of the information (hence there would be a *Community* of users improving a common store of materials and procedures).
    2. Supervisor of the network services (hence the system would be *adaptive* to the needs of the users)." (Brown et al., 1967, pp. 49–50).

"In designing a priority handling system, we should never permit ourselves to believe that we have more (or less) *usable* communications capability than we really have. This implies network status control feedback loops." (Baran, 1964, pp. 17–18).

3.18 "To facilitate system scaling, reliability, and modularity, many multi-processor operating systems are designed to treat the processors as homogeneous system resources. Hence, there is no 'supervisor' processor, each schedules and controls itself. To prevent critical races and inconsistent results, only one processor at a time is permitted to alter or examine certain shared system data bases; all other processors attempting simultaneous access are locked-out. This phenomenon is not strictly limited to homogeneous processor systems, similar requirements apply to any multi-processor scheme utilizing shared data bases." (Madnick, 1968, p. 19).

3.19 "Some general observations may be of interest. There are indications that the cost of operating an information system network, organized along subject lines, varies little with change of process allocation within the system. Whether all acquisition and input processes are carried on in a center clearing house or distributed in some logical manner among the service centers does not appear to make a significant difference in cost. On the other hand, centralization in the regionally organized system becomes imperative if excess operating costs are to be avoided. In a system organized to serve users on a project basis, there is an indication of some economy of operation being achieved by complete decentralization." (Sayer, 1965, pp. 141–142.)

"The least expensive method of organizing a science information system network appears to be on a regional basis with the centralization of acquisition input processes being undertaken in a central clearing house." (Sayer, 1965, p. 142.)

3.20 "In the network concept, then, the technical information centers would be linked by the traffic routing centers. Each would become dependent upon the other with both responding to the law of supply and demand, service and customer satisfaction, and continued viability based upon justification of existence through performance." (Vlannes, 1965, p. 5).

"Other choices in the spectrum may include that of a network of information centers in which each community performs and contributes to the advancement of knowledge in accordance with its capabilities. Of course, a network must impose a series of constraints in order to operate, but it also allows for the flexibility that a rigidly structured system cannot accommodate. A network also fosters a sense of competition in which each community must ever strive to re-orient itself in order to survive and progress in its changing environment. In addition, each must become sensitive to the changes in the other communities in order that it may react, re-evaluate and adapt to the net set of goals that are inevitable." (Vlannes, 1965, p. 4.)

"In order to gain control over the accountability data, a telephone switchboard was added to the system . . . With the formalization of the terminal network, the concept of operation changed from a central computer with satellite terminals to the concept of a central terminal network with satellite computers." (O'Sullivan, 1967, p. 169).

3.21 "Many of the larger systems must also take into account the requirements for providing machine-readable output for use in a decentralized network of search centers. The designer must remember that other users will place constraints on the parent system. It must be remembered that a change to the central system has multiple effects on the various members of the decentralized network. Good system documentation will be essential in providing programs to the local search centers. A constant training requirement will also be imposed upon the central system, and technical liaison must be maintained with all users in the network. Effective file maintenance procedures must be developed well in advance of implementation of the decentralized system. Changes and updatings to the central file will occur frequently, and an adequate mechanism must be available for insuring that these same changes are made to all files in the field." (Austin, 1966, p. 245).

"Locating the point of minimum sufficient centralization for a system may call for a some what atypical philosophy of system design, a philosophy not commonly held by theoreticians on the subject but often implicit in the daily design practices of the engineers and logicians involved in the actual specification of system details. That is, a system should have standardized procedures for only the smallest job units that can be formally specified. These fixed subroutines can then be combined to form larger routines suitable for performing larger segments of the overall activity. At any point where two jobs are dissimilar, this dissimilarity can be reflected not only in different flow diagrams but also in different formats, codes, sequencing procedures, indexing methods, displays, and so forth. To this extent, the system is neither tailor-made nor ready-made. It is not uneconomically designed so that every job is unique, nor is it standard but ill-fitting because dissimilar jobs are forced to standardization. Rather, like a made-to-measure suit, the system is built around small standardized parts, each designed to fit a small part of the overall job. The larger portions of the system are not standardized as total units, but are unique configurations of standardized smaller parts." (Bennett, 1964, p. 108).

3.22 Baran (1964) considers, for example, "four separate techniques that can be used singly or in combination to achieve, through automation, 'best' use of a seriously degraded and overloaded communications plant, within the framework of a rapidly changing organizational structure." (p. v).

3.23 "Calulation of the average daily volume and the peak volume of information to be handled in the system consists of four steps:

1. Calculate the average daily volume of messages presently flowing in the system.
2. Calculate the average number of characters in each message.
3. Calculate the average daily total transmission time.
4. Calculate the peak volumes.

The communications designer must plan the system to handle the peak traffic loads with acceptable delay as well as the total traffic load." (Gentle, 1965, p. 58.)

"Calculate Call Volume. The first step in calculating the volume of information that must be handled by the data communications system is to determine the number of messages (called 'traffic') handled in an average day. This is done for traffic to and from every point in the system. The volume is calculated by taking a sample of several days' traffic and actually counting the number of messages handled each day at each location. The number of days to be included in the study is based upon the estimated number of messages that are handled in a month. An estimate of the monthly volume should be made, and the following table may be used as a guide in determining the number of days to be studied.

Estimated monthly message volume	*Number of days to be studied*
Under 1000	20
1000 to 2000	10
2000 to 5000	5
5000 to 10,000	3
10,000 and over	2

Ideally the working days to be studied should be chosen at random, but if for any reason a series of consecutive days must be selected, care should be taken to avoid days immediately preceding or following holidays. In addition, the count must be made at each location from which information is sent and at which information is received." (Gentle, 1965, pp. 58–59.)

"Calculate the Total Transmission Time. The third step, after calculating the average number of characters per message, is to determine the average daily total transmission time. At this point a transmission speed must be assumed. This transmission time can be calculated by dividing the average number of characters per message by the assumed speed of the system. If the average message has 2,500 characters, for example, and the assumed transmission speed is 10 characters per second, the average transmission time per message will be 250 seconds. To this figure, however, must be added some operating time for dialing the call, waiting for the connection to be established and, in some cases, coordinating the forthcoming transaction with the personnel at the receiving end. Operating time should be calculated from a study of a sample of calls, but if this is impracticable, the system designer may use 100 seconds as an overall average for the operating time on each dialed-up data communications call. . . .

"The amount of delay to be expected during the busy hour depends upon the holding time of the circuit at the receiving location and the total number of minutes in the busy hour during which information will be received. Data communication planners refer to a series of charts which indicate the expected delay in transmissions when holding time, circuit use, and number of circuits in the group are known factors. The number of incoming circuits affects the probability that a calling part will receive a busy signal." (Gentle, 1965, pp. 63, 65).

"The intervals at which messages are transmitted. Are these intervals fixed or random? What are the peak rates, and at what times of day will they occur?" (Reagan, 1966, p. 23).

"To determine the proper size of a dial system required, it is necessary to study the company's busy hour, calculate the average message length, determine the total number of call seconds involved, and then consult the hundred-call-second (CCS) tables developed for telephone trunk loading. On the CCS tables is a listing for the number of trunk lines required for a given loading and grade of service desired. If you want only one lost (busy) call in every hundred, the tables will show how many trunk lines are required. If you can tolerate 10 lost calls per hundred, the tables show that you can get by with fewer lines. In this manner, you choose the grade of service you require to handle your particular data communications problem." (Birmingham, 1964, p. 37).

"Whenever it is necessary to have a large number of stations communicate among a large number of potential addresses, it is a practical necessity to use some form of switching. There is always a very wide variety of potential groupings and possible network configurations. The shape and complexity of the resulting network is very much dependent upon the economies one wishes to make in circuit groupings. The choice of these groupings in turn depends upon the statistics of the expected traffic. If the traffic statistics are known very accurately, large savings in cost of selection of routes and assignment of channels can be realized." (Baran, 1964, p. 15).

"Complex data communications systems that terminate many lines in a central facility usually use either a multi-line communications controller in conjunction with general-purpose computer or a specialized, stored-program communications processor. These units are capable of buffering and controlling simultaneous input/output transmissions on many different lines. Again, a wide variety of equipment is now available to perform these functions. The available devices differ in the number and speed of lines they can terminate and in their potential for performing auxiliary or independent data processing. Examples include the three multi-line communications controllers available for use with the general-purpose IBM System/360 computers and the Collins Data Central system, a computer system designed especially for message switching applications." (Reagan, 1966, p. 26).

"Data rate alone, however, does not provide a complete measure of network loading; some devices have a short duty cycle, such as one computer sending the contents of its core to a remote computer. While such devices place a heavy peak demand for service, they are highly intermittent. On the other hand, a pulse-coded telephone call places a lower peak demand load, but ties up network capacity for a longer period and results in heavier average loading. Therefore, we should include an expected message-duration or holding-time factor in the network-load weighting table." (Baran, 1964, p. 30).

"It is necessary to have some idea of the types of messages that the system will be handling so that estimates of transmission rate requirements can be made. This calculation is intimately tied in with the distribution of terminals from the central computer system. It may be economically justifiable, even a necessity, to multiplex several of the terminals together onto one high-speed line." (Stephenson, 1968, p. 55).

"It is vital to have some knowledge of the average mix of message types and message lengths in the system." (Stephenson, 1968, p. 55).

"The results obtained from the numerical solution of a model give a precise and comprehensive description of the statistical effects of high traffic. The value of such precise and extensive data for computer systems may not be obvious, especially since 'worst case' examples and physical reasoning can establish much of the qualitative behavior of the system. The two prominent facts which warrant such analysis are the large scale of most multi-console systems, and the critical nature of machine response in their conception. Because multi-console systems are of such large scale, it can be worthwhile economically to thoroughly evaluate proposed designs, seeking to achieve maximum capacity. Such design evaluation requires a rather accurate knowledge of the traffic in the various parts of the system. Because much of the effectiveness of a multi-console system can be rapidly dissipated by poor response characteristics, an accurate statistical description of response is also needed. The existence of a capability for rapidly solving general queueing models makes this approach a much needed alternative to Monte Carlo simulations or experiments in traffic studies." (Fife and Rosenberg, 1964, pp. H1–6).

3.24 "The unequal and intermittent loading of net-type channels in present communications results in inefficient utilization of radio frequencies. If channels were made available to other users during periods of idleness, more communications could be handled within a given frequency band. A solution to the problem of frequency congestion can be found in giving each user access to a group of channels through a system which selects an idle channel for each call and releases the channel as soon as the call is terminated. Such a system may be called a random access system, since an idle channel is selected at random from the group each time a user wishes to place a call. After a channel is selected, a means is needed to direct the call to the intended group or individual without disturbing users to whom the call is not directed. This process is called discrete addressing and is applied in the form of tone signalling to many systems in use today. The combination of the terms Random Access Discrete Address describes a class of communication systems employing these principles and is frequently referred to by the acronym, 'RADA'." (Horne et al., 1967, pp. 115–116).

"Adaptive channel communication systems provide efficient bandwidth utilization by allowing time sharing of a small number of channels by a large group of users with low duty rates. Unlike fixed frequency netted systems, where a call to a non-busy subscriber cannot be made if his assigned frequency is in use by another of the net members, the adaptive system will allow completion of all calls provided the number of simultaneous calls is less than or equal to the number of system channels. The adaptive system is thus similar to the telephone system where each user has a private line, but the number of trunks connecting the lines is less than the number of lines." (Horne et al., 1967, p. 120).

3.25 "In the distributed network routing scheme . . . if the preferred path is busy, the in-transit Message Block is not stored, but rather sent out over a less efficient, but non-busy link. This rapid passing around of messages without delay, even if a secondary route must be chosen, is called a 'hot-potato' routing doctrine. . . .

"With such a doctrine, only enough storage at each node need be provided to permit retransmitting messages if an acknowledgement of correct receipt is not received from the adjacent station within a prescribed time interval. Message storage capacity is modest. . . .

"A dynamically-updated routing table stored at each node indicates the best route for each Message Block to take to reach its directed end terminal station . . . When two messages seek the same preferred line, a random choice is used to select which message is sent out over the best path . . . Simulation has shown that this use of secondary paths in lieu of storage is a surprisingly effective doctrine, enabling transmission of about 30–50 per cent of the peak theoretical capacity possible in a store-and-forward system having infinite storage and infinite delays." (Baran, 1964, pp. 9, 12).

3.26 "If empirical data were available in the information field we could use an input-output matrix. On the input side the various international and national information services should be included. Many of these services act also as users of the input from other services, and they process it for their own purpose. Thus the output side will also contain most of the same services. The content of the matrix should be information just as an economic matrix will contain employment, goods or services. The economist expresses his flows in dollar values, since money is the conventional substitute. A convention measuring the information flow of documents has to be developed." (Tell, 1966, p. 119).

3.27 "Based upon information taken in these [Lockheed] studies, it is quite clear that long term information exchange requirements will include wide band data and image transmission and that data entry points may ultimately involve more than 10,000 terminals throughout the nation." (Johnson, 1967, p. 7).

"The issues of communication in the sense of the electrical transmission of data have come to the forefront during 1966. Most computer-system implementers and users are encountering the problems of communication engineering for the first time. Many have found disquieting the fact that the element of system cost arising from the necessary data-communication support of large, multiaccess systems is surprisingly large—often of the same order as that of the central computer facility." (Mills, 1967, p. 244).

4. Input-Output, Terminal Design, and Character Sets

4.1 "The display-computer interface is a generalized requirement of all displays and provides computer buffering for the display system. In addition, some systems may require logic level and/or word length changes from computer to display. These operations are also performed by the interface." (Mahan, 1968, p. 9).

4.2 Plans for implementation of an experimental network for the Advanced Research Planning Agency (ARPA) have been reported as follows: "The ARPA contractors' network is . . . in the planning stage. As one of the nodes of this network, SDC would receive a small computer (of the PDP–8 class) as an interface message processor (IMP). All other nodes in the network would likewise have a similar IMP. The IMP would be two-faced: one view facing the local contractor's time-sharing system; the other facing other node IMPs. In this fashion, network protocol would be standardized at the IMP, while still maintaining the flexibility of permitting dissimilar local time-sharing systems to be included as nodes. An IMP will support up to two local time-sharing systems, thereby permitting local networking via the IMP." (System Development Corp., 1968, p. 1–13).

4.3 "A method must be devised to develop the storage adress of a record from a key in the record itself. This is usually referred to as a randomizing formula. What is implied is an arithmetical operation on a key in the record to develop from this key an actual storage address for the record. Study is required to ascertain which technique or formula provides a good file utilization, with the least number of common addresses for different keys to keep overflow records down." (DeParis, 1965, pp. 30–31).

"The logical address of a data item defines the relative position of the item within the structure of the data base. The logical address is coded so that a unique code may be created for each item in the data base. The logical code is a numerical representation of the nodes in the multi-list tree structure of the data base, and is called the Item Position Code." (Barnum, 1965, p. 50).

"The technique of hash addressing by randomizing the input word was used to generate an address for the dictionary look-up. This method results in the address of the first element of a chain of words in storage, each of which yielded the same random address. An examination of the chain would proceed in sequence until the word was found or until the last element of the chain was compared." (Baker and Triest, 1966, p. 3–13).

"Every word encountered in the scan of an input text, i.e., during the actual operation of ELIZA, is randomized by the same hashing algorithm as was originally applied to the incoming keywords, hence yields an integer which points to the only possible list structure which could potentially contain that word as a keyword." (Weizenbaum, 1966, p. 38).

4.4 "The concept of on-line information control implies the ability of such users of the system to change the performance of the system to meet their own changing needs or wishes. With adequate control, they can experiment with the display of alternative data formats or configurations, with alternative sequences of data retrieval, with alternative formulae for summarizing, processing, or analyzing data." (Bennett et al., 1965, p. 436). "Other suggestions indicate the need to reconcile data formats of considerable variety." (Brown et al., 1967, p. 54).

4.5 "Special provisions (perhaps in the software) may be required to prevent overlap of symbology, as might result from adjacent aircraft tracks." (Israel, 1967, p. 208).

4.6 "Time-shared computers need an accurate, versatile clock to schedule programs, subroutines or problems, and to synchronize the computers with a desired time base. Large computer systems usually have their own built-in clock, but smaller units used in a time-sharing mode must be modified by the addition of an external clock." (Electronics **38**, No. 23, 194 (1965).

4.7 The question of color on output is reflected first in the more conventional documentation or library situation. Thus it is to be noted that "the use of color in printing is of increasing importance", but that there are questions of whether copies in color, such as the color film versions of valuable manuscripts supplied by the Bodleian Library or the French Bibliothèque Nationale (Günther, 1962, p. 8), can be preserved over extended periods of time. (Applebaum, 1965, p. 493).

4.8 "The term 'graphical communication' presupposes a graphical language in which pictorial information is transmitted between the designer and the computer." (Lang et al., 1965, p. 1).

4.9 "M. Stafford of Westboro, Mass. . . . discussed the ways in which graphic communications systems are currently used, with emphasis on their interface between computers and information storage centers. Some examples of their use, he noted, are to send signature samples and information on accounts between a main bank and its branches, to send weather maps and technical drawings across the country, and to send pages of newspaper copy between cities." (LC Info. Bull. **25**, App., 288 (1966).)

"[A] CRT display console . . . [should meet at least] three on-line capability criteria. First, it is directly tieable to a data processing system. Second, it has ability to initiate messages or control signals from a data entry keyboard or switches for transmission to the computer. Finally it has ability to receive digital messages or control signals." (Frank, 1965, p. 50).

"Desire to display data rapidly . . . places a premium on the efficiency of the graphical language used at the display level." (Dertouzos, 1967, p. 203).

"The CAFE system permits definition of, or selection from, a library of pictorial elements (static and dynamic), formation of complex pictures from simpler ones, and parameter control of their individual display characteristics as well as their synchronization into a sequence of composite displays. Once a pictorial element is defined by the user-editor, it is readily available by reference to a name supplied at the time of its definition." (Nolan and Yarbrough, 1968, p. C103).

"High-level methods for expressing scope output and console input operations have produced a great deal of display programming activity. The obvious advantages over assembly coding of clarity, brevity, and fewer mistakes are a strong incentive for users. The compiler-compiler system on TX–2 has made relatively easy the implementation and evolution of an extended high-level language based on ALGOL. The language, called LEAP (Language for Expressing Associative Procedures) has associative data structuring operations, reserved procedure forms for display or input manipulation, and real time variables such as the clock time and tablet stylus coordinates. Direct means for invoking the symbol recognizer's services are even incorporated. A 'Recognize' statement gets a symbol from the tablet just as a 'Read' statement gets a symbol from the console keyboard. Writing interactive programs which use the display is straightforward, and experimentation and modification can be rapid.

"Having LEAP available as a programming tool has facilitated the evolutionary development of application programs for graphical programming, data analysis, logic diagram input, and integrated circuit mask layout. The largest effort has been on circuit mask programs. A circuit designer controls the mask layout program with freehand figures sketched on the Sylvania tablet. The computer recognizes his rough marks as commands to create, move, group, and delete various integrated circuit components. Once a circuit design is complete, output tapes for each of the mask levels required can be punched for later use by a precision patterns making machine. Individual variations among designers in drawing style are accommodated easily by the trainable recognizer." (Sutherland et al., 1969, p. 632).

"First of all, this language must be concise and easily learned. It should permit the user to specify the various features of a drawing in the natural order in which they occur to him and in a continuous stream rather than in segmented form in separate statements. For publication purposes, it must give the user direct and ultimate control of every line drawn if he so desires. Yet, where applicable, the user should be able to cause a particular version of a whole superstructure to be generated by the system merely by specifying a few simple options. Toward this end, the language should include the facility to construct higher level statements from the basic language statements. It is envisioned that a set of such 'user defined' statements could be developed by an experienced programmer for a particular application. Once defined, such statements could then be used by non-programmers without knowledge of their genesis. Preferably, the language should meet the needs of users of widely varying computer experience. At one end of the scale it should appeal to a user essentially untrained in computer programming for the simple transcription of drawings from a rough draft. At the other end of the scale it should satisfy a user desiring to generate pictures controlled by algorithm at execution time. Drawing on a conditional basis is particularly attractive for applications such as circuit drawings and the production of musical scores. Finally, the implementation of this language should readily accommodate minor changes in syntax dictated by user experience. In addition, it should be designed to run easily on a variety of computers, and hopefully on a variety of terminal CRT systems, such as the Stromberg Carlson 4060 or the RCA Videocomp." (Frank, 1968, p. 179).

"For the past five years, hardware has existed that allows a computer user to enter drawn, printed or written information directly into a computer as easily as writing with pencil on paper. The missing element that would make such devices viable entities in computer systems has been the appropriate software support. At SDC, we are developing the necessary programs to allow a user scientist to hand-print, on-line, two-dimensional structures required in the statement and solution of his problem. These programs include an on-line, real-time character recognition program that is independent of both position and size of the input; editing programs that can deal with two-dimensional entities (as opposed to linear strings); and contextual parsing programs that re-structure the recognized, edited input for subsequent processing. This work is being done within the constraints of the SDC Q–32 Time-Sharing System . . .

"The editing facilities are simple and straightforward, requiring a minimum of effort on the part of the user while providing repositioning, erasure, replacement and insertion for such diverse notations as mathematics and organic chemical structures." (Bernstein and Williams, 1968, p. C84).

4.10 "The display information is stored in a ring-type list structure, which reflects not only the order in which parts of the display are to be produced, but also the associations which may exist between parts of the picture. A display routine within the executive threads its way through this ring structure transmitting the data if finds in the structure to the display generator." (Forgie, 1965, p. 606).

4.11 "A three dimensional windowing subsystem is available for the AGT [Adage Graphics Terminal] in which upper and lower bounds can be placed (in digital registers) on x, y, and z. The vector generator then blanks whenever the beam goes beyond one of the bounds, and it also tells the program which bound was exceeded. This device finds use in a number of applications including uncluttering pictures, testing the dimensions and intersections of solids, and splitting the CRT screen up into rectangles allocated to different pictures, which can then move beyond the 'edge' without encroaching upon its neighbor's display space." (Hagan et al., 1968, p. 753).

4.12 "Early graphics systems, such as the GM DAC system and Sketchpad, were little better than automated drafting boards. This statement is not intended in any way to belittle their efforts, but merely to underline the fact that there was very little that could be done with a picture once it had been generated. Certain of Sutherland's illustrations are quite startling in their apparent sophistication, but generally return to the use of constraints (which were satisfied using least squares fit, which is an energy constraint in engineering). In endeavoring to ascribe meaning to pictures, later investigators were forced to use data structures in a more sophisticated manner, and it became obvious that associations should be much more complex than the original ring structures, etc. The CORAL language, APL, and AL, the language described by Feldman, are all outgrowths of the need to ascribe extra associations and meanings to a picture. Many are now working on this problem but information in technical literature is relatively sparse. To illustrate the techniques being developed at the University of Michigan, and to show the power of the associative language, a detailed example will now be given." (Sibley et al., 1968, p. 553).

4.13 Some other examples of experimental capabilities in this area are as follows: "GRIN [(GRaphical INput) language] is particularly suitable for use in problems requiring the extensive real-time manipulation of graphical information at the console. It takes full advantage of the incremental display structure of the scope . . . Thus, if a display part is composed only of a sequence of incremental words, its position on the display scope can easily be changed by changing only the initial absolute entry point. Also if a part is represented only incrementally, it can be called up using the display part subroutine linkage at many places on the scope face. The part has to exist in storage only once, however." (Ninke, 1965, p. 845).

"The GRIN–2 (GRaphical INteraction) language is a high-level graphical programming language that permits the generation and manipulation of the graphical data structure, and provides statements for controlling real-time man-machine interaction. The interaction portion of the language is used with the GRAPHIC–2 graphical terminal. The rest of the language pertains to the common data structure used by all graphical devices and terminals." (Christenson and Pinson, 1967, p. 705).

"The PLOT operator is used to create a picture on the oscilloscope corresponding to the graphical language statements . . . It builds a list of 'console commands' (plot a point, or a line, reposition the beam etc.) known as the *display file*, which are interpreted by the display console hardware so producing the desired picture." (Lang et al., 1965, p. 39).

"VITAL (Variably Initialized Translator for Algorithmic Langauges), a general purpose translator for the Lincoln Laboratory TX–2 computer, is currently being adapted for use as a graphical control language translator." (Roberts, 1966, p. 173).

"The MAD language offers a powerful facility to programmers to tailor their compiler to fit their application, viz., the MAD operator-definition facility. Using this part of the MAD compiler, the programmer (or programming staff) can extend the compiler by introducing new operators and new operand mode definitions into the language. In the formulation of any graphical language, the MAD operator-definition facility should play a large role. The syntax extensions we are describing in this paper are those which cannot be encompassed within the operator-definition facility. The list-processing facilities described in the last section resulted from the examination of the L6 syntax, and the identification of these elements which were beyond the scope of the operator-definition ability. The rest we leave for development at the MAD programming level.

"In a similar fashion, we have tried to identify those elements of graphical language which were beyond the scope of the MAD syntax for their possible incorporation into the compiler. The one example of a graphic language which encompasses most of the desirable elements is the LEAP language of Feldman and Rovner. This language is an ALGOL-type language which includes elements of set operations as well as Feldman's own method of representing graphical relations. LEAP is predicated on a highly elaborate but efficient method of data storage involving hash coding, but the details of the implementation do not concern us here. What does concern us, however, is the language syntax, insofar as it is incompatible with a MAD representation." (Laurance, 1968, p. 392).

"The subject of data structures has received a great deal of attention in the past few years, especially in relation to computer-aided design. Programming systems used for creating data structures (sometimes dignified by the name 'graphical languages') vary greatly in the rigidity of their representation and the types of facilities offered to the programmer. As an example of a high-level system, we can mention the formal language LEAP, in which the programmer can easily manipulate the logical elements of his model, and the structuring of the information (in the form of hash-coded tables) is performed automatically by the language system. At the other extreme we have a language like L6 which is a macro language useful in creating arbitrary list structures. The difference between these two 'graphical languages' is so great that one could easily conceive of implementing the LEAP language using the L6 language. An excellent review of this subject is given by Gray." (Laurance, 1968, p. 387).

"Only two other compiler-compiler systems which cater for graphics with Computer Aided Design in mind are known to the author. The first of these, AED, due to Douglas T. Ross is a very long-standing and general systen of great interest. GULP only attempts a small part of this generality; as AED has been justly called 'a system of systems for building systems'. AED processes graphic language using a macro-processor in a different way from the character definition of GULP. AED is also able to deal with context-dependent languages, and with more general types of precedence besides including an ALGOL-like compiler and many special-purpose packages for design; e.g., POLYFACE." (Pankhurst, 1968, p. 416).

"It is of vital importance that the language facility for the Computer-Aided Design System include not only flexible descriptive and programming languages in word form, but a generalized capability for graphical communication as well. There are many aspects of design in almost any field, for which the natural means of expression is in terms of pictures or diagrams, and any attempt to convey equivalent information in verbal form would be extremely unnatural and awkward, and would defeat the basic principle that the designer-user be able to operate in a manner which is natural to him." (Ross and Feldman, 1964, p. 15).

4.14 "Even within equipment classes there is a wide variation in keyboard arrangements. Though the alphanumerics generally correspond, the availability and location of special characters is by no means standard. Functional controls are even more varied, and in the case of devices using complex editing features (the alphanumeric display device) the number, type, function, and placement of functional controls is completely dissimilar between manufacturers." (Auerbach Corp., SDA, 1967, p. 2–10).

"For the inquiry/display console, the major problem is that of determining the proper functions to implement for the user." (Hobbs, 1966, p. 44).

"Other operator input devices are available on various consoles. Alphanumeric keyboards and function keys are used. Some function keys use plastic overlays for additional coding. Track balls and joy sticks are preferred by some users. The Rand Tablet, which provides an easy method for graphic input, is available as an accessory in several systems." (Machover, 1967, p. 158).

"About a half of the available buttons are left unprogrammed, so that every user can tailor the system to his own particular needs by constructing just those operators which are useful to him at a given moment. A paper overlay is used to mark the labels under the buttons . . . The system provides operators which allow each user to keep his own private programmed push-buttons and functions in a deck of cards. The same programmable buttons may then be utilized by different users for completely different purposes simply by reading in a small deck of cards at the start and punching out a new deck when someone else wants to use the system." (Clem, 1966, p. 136).

"Registration . . . is important in systems using multiple display projectors or sources. Display overlays are a prime example where static information is projected over the dynamic display. It is very important that the images are properly registered with respect to each other. In general, registration accuracy should meet or exceed the resolution of the display in order that misregistration not be detected." (Mahan, 1968, p. 5).

". . . Better determination of the proper functions to mechanize in the display to facilitate the human interface, including the appropriate human factors determination of the appropriate trade-offs between manual and automatic functions." (Hobbs, 1966, p. 1882).

"In addition to the standard typewriter keyboard, the CRT set will contain 40 special function keys as well as several cursor control keys. Through the use of plastic overlays, the meaning and purpose of the special function keys can be changed when the sets are used for different application modes." (Porter and Johnson, 1966, p. 81).

"Manual input to the [IBM 2250] display unit is effected by one of three devices—an alphanumeric keyboard, a program function keyboard and a light pen . . . The program function keyboard contains 32 keys designed to allow the operator to indicate program interpretative functions to the computer by means of a single key depression . . . Any significance can be ascribed to . . . [the keys] depending upon the requirements of the operator and the program." ("IBM System/360", 1965, pp. 298–299).

4.15 "A system is described in this paper for developing graphical problem-oriented languages. This topic is of great importance in computer-aided design, but has hitherto received only sketchy documentation, with few attempts at a comparative study. Meanwhile displays are beginning to be used for design, and the results of such a study are badly needed. What has held back experimentation with computer graphics has been the difficulty of specifying new graphic techniques using the available programming languages." (Newman, 1968, p. 47).

"The major problem is the development of sufficiently versatile programming languages directed at graphic, interactive devices." (Flynn, 1966, p. 99).

"Unlike conventional computer languages, graphical languages have received little study, and their formal properties have not been examined in depth. The lack of precise ways to formulate and represent graphical language fundamentals impedes the use of graphical techniques in many problem areas." (Sutherland, 1967, p. 29).

4.16 "The types of phosphors used in current alphanumeric display terminals are of relatively low persistence. To present a display that is suitable for viewing and free from annoying flickering, the display must be continually regenerated. Buffer storage is provided within the central controller or within each display unit to store data entered locally or received from the remote computer. Logic circuitry within the controller or display unit utilizes the buffer storage to regenerate the display, usually 30 to 40 times per second." (Reagan, 1967, p. 33).

"Continual regeneration of a short persistence CRT for flicker-free viewing demands high data transfer rates, or considerable buffer storage; but in return for this outlay comes ready communication by single photosensor pens and a medium for highly dynamic displays. However, the attendant costs are related to regeneration rates established by persistence of vision criteria and are disproportionate to the dynamic content of the majority of displays where static text and diagrams prevail for seconds." (Rose, 1965, p. 637).

"While the maximum required number of flicker-free lines varies greatly among applications, a vector construction rate of 10 microseconds per inch for the larger component, plus a memory access and decode time of not more than three microseconds per vector, should satisfy the requirements for most applications. A refresh rate of 30 frames per second would display about 2,600 connected one-inch lines." (Chase, 1968, p. 26).

4.17 "By modulating the electron beam with several differential selectable frequencies, one could 'color' or 'classify' various displayed points on the CRT screen." (Haring, 1965, p. 854).

"The light pen allows good feedback in pointing since programming can brighten what unit is being seen, or display only the total unit being seen. The importance of such feedback cannot be appreciated until one works with a graphical system." (Ninke, 1965, p. 844).

"In addition to selecting point locations by means of the tracking cross, the light pen can be used in another interesting mode of operation known as the pick function. After a figure has been drawn by the operator, or is generated on the basis of computed data, the operator may desire to select a particular curve, component, line of text, or other distinct element which is a part of the picture. He may do this merely by pointing the light pen at the element and pressing an 'accept' button. The light pen photomultiplier produces a pulse at the instant the selected element is painted, which signals the computer. Since the address of the element being painted is known by the computer, its identification can be used as directed by the program. For example, the element may be erased, moved, duplicated, or rotated. By proper programming, symbols or labels on the screen can be made light-pen sensitive and can be selected by pick function. This operation may be used to select a single option from a list or 'menu' of alternatives presented on the display." (Prince, 1966, p. 1699).

"After investigating several possibilities, we concentrated on the use of intensification for highlighting parts of a display. For example, the four boundary lines of a surface may be brightened while the interior lines are dimmed. This technique of varying intensification has proven to be an important piece of feedback to the console user. We call the preceding example 'static' intensification because an item remains intensified throughout the current display. Static intensification can be used meaningfully in other ways, besides highlighting. For example, user attention can be focused on suggested choices of control words by brightening them, while dimming the rest of the display. Shading to give a three-dimensional effect is also useful in optimizing the user's understanding of a display. This technique, however, requires enough intensity levels so that the transition between them is continuous and imperceptible . . .

"This 'selective disabling' aids the operator in recognizing his displays as a composition of various sets of items. In addition, he will be less confused when trying to make a selection. Only a small subset of items can be selected, even though other information is still displayed. Thus, the selectable items are kept in context with the rest of the display. The combination of selective disabling and dynamic intensification provides the means of conveying the syntax of a graphical language to the console user." (Joyce and Cianciolo, 1967, p. 715).

4.18 "Overlays can be quickly accomplished on standard maps by reading the maps with the computer-controlled CRT reader and combining them in memory with elements to be displayed. The results can be put out on film." (Fulton, 1963, p. 40).

4.19 Motivational factors obviously include the assurance (or lack of assurance) to the client that he is in fact effectively online to the processing system; that he has, in effect, direct access to his own prior program and data stores and to such other programs or data as can be shared; and that his own data banks and programs are adequately protected against unauthorized access, piracy, or inadvertent destruction.

"Evaluating the 'cost effectiveness' of graphical I/O of various types is a particularly difficult task. The literature is noticeably lacking in any reference to the subject. Given a particular function to implement, such as to reduce a graph to hard copy, to monitor a given equipment or program parameter, or any other straightforward operation, a cost/performance comparison of alternative implementations can be made. However, to assign a widely agreed upon numerical scale of values to human productivity or 'intellectual enhancement' is difficult, if not impossible." (Wigington, 1966, p. 88).

"The art of designing man-machine systems is still in its infancy. List selection terminals, by placing the output burden on the data system, are able to increase the input rate that an untrained user can achieve. By so doing, terminal operation is made feasible for a much broader class of users. So far this approach has proved useful in applications in which the vocabulary is limited to several hundred words. We are just beginning to develop the automatic formatting procedures that will expedite the design of the next generation of matrices. The potentials of information systems that adapt to the user's response patterns are yet to be realized. To the retriever, this approach offers the ability to control the quality of the data at the time that they are entered without, we hope, placing an undue burden on the enterers . . . Although we have been heartened by our limited successes in facilitating man-machine communication, we have at the same time been humbled and challenged by our ignorance of how a dialogue should be structured, how we should mold the machine to fit the man. It is perhaps in this area that the next advances will be made." (Uber et al., 1968, p. 225).

4.20 "In order for computer-aided design to achieve its full potential in the coming years, significant hardware advances are called for in several areas. More natural means for communicating with the computer are desirable. Although many clever techniques have been developed for using the light pen, it is still not completely satisfactory. Also, the need is sometimes expressed for large, high-resolution 'drawing board' displays." (Prince, 1966, p. 1706).

"A variety of light pen configurations are available ranging from a simple penholder type to a gun type. Some pens are relatively heavy while others are lightweight. Some use a very flexible cable and others use a rather stiff cable or coil cord. Aiming circles are provided with some light pens so that the operator knows where the sensitive area of the light pen is pointed. Activating switches for the light pen include mechanical shutters on the pen, electrical switches on the pen, knee switches and foot pedal switches." (Machover, 1967, p. 158).

4.21 "Another difficulty of the lite pen . . . is that its broad end which contacts the scope face obliterates that portion of the screen where the lite pen is acting. One means of overcoming this difficulty might be to display the points drawn by the pen to one side of the area actually sensed." (Loomis, 1960, p. 9).

4.22 "Display maintenance has been provided by the large computer or by a data channel off the large computer. The high transfer rates needed for such an organization have dictated that the consoles be very close, if not physically adjacent, to the supporting computer or channel." (Ninke, 1965, p. 839).

". . . Display maintenance is independent of control computer intervention. Thus, once started by the control computer, the display continuously refreshes itself with a direct jump word at the end of the display picture providing the link back to the start." (Ninke, 1965, p. 842).

"To avoid flicker and to update picture information, each point of the display must be repeated at least every 1/50 second. Although high-speed repetition is within the capability of light-deflection methods, rapid repetitive presentation is unnecessary if the display screen has good persistence." (Soref and McMahon, 1965, p. 60).

"Memory for a vector display file requires about 4K words of storage per user." (Roberts, 1965, p. 217).

4.23 "Operable flat oscilloscopes have been constructed and have proved to afford excellent resolution." (Licklider, 1965, p. 96).

4.24 For example, "the most difficult aspects of the keyboard to experiment with are the key pressure required and the reaction and travel of the keys at the moment the signal is transmitted." (Boyd, 1965, p. 157).

"The keyboard design would be based on principles of motion study. Each key would be shaped and positioned for maximum accessibility by the shortest route, with compensations made for distances traveled, varying strength in different fingers, and other factors." ("The (R)evolution in Book Composition . . . IV", 1964, p. 69).

"The keyboard must be kept fairly small, at least within the span of an operator's hands. In effect, this does mean a single alphabet keyboard whose condition is controlled by function buttons." (Boyd, 1965, p. 157).

". . . Various criteria such as weight of key depression, key travel, key spacing, layout, and whether or not you want hard copy." (Boyd, 1965, p. 153).

"One possible result of this type of analysis could be a bowl-shaped keyboard, with keys on the sides and rear banked up from the horizontal . . . This would enable the fingers to reach outlying keys by moving in a straight line, rather than in an arc or in two moves, over and down. Another feature would be larger keys on the outskirts, to reduce the need for accuracy in moving fingers long distance." ("The (R)evolution in Book Composition . . . IV", 1964, p. 69.)

"Kroemer (1965) . . . arranged the keys in two separate but symmetrical groups, one for each hand. Each group consists of three curved rows of five keys. The form of the curve corresponds to that of the fingers and the possible movements of the individual fingers. The two space bars for the thumbs are curved as well, which enables the thumbs to strike them from any hand position. The keyboard position is no longer horizontal since tests disclosed that an angle of 30°–45′ to the horizontal gives the most comfortable position to the hands and arms." (Van Geffen, 1967, p. 6).

Hobbs points out further that "new types of keyboards are being developed that do not involve mechanically moving parts and that may permit more design freedom from the human factors standpoint. These include pneumatic, optic, and piezoelectric techniques." (Hobbs, 1966, p. 38).

4.25 Mills, in a review of 1966 developments, concludes that "work directed toward solving this interface problem has appeared to be poorly focused. Only a few attempts to specify an improved general-purpose terminal were reported, and even fewer reports of actual hardware development and prototype testing were discovered." (Mills, 1967, p. 245).

Further, "it will require major research and engineering efforts to implement the several functions with the required degrees of convenience, legibility, reliability, and economy. Industry has not devoted as much effort to development of devices and techniques for on-line man-computer interaction as it has to development of other classes of computer hardware and software." (Licklider, 1965, p. 66).

4.26 "Specific to the time-sharing field there is a need for the development of adequate consoles, especially graphical input-output consoles. There are conflicting requirements for low cost and for many built-in features that minimize the load on the central computer. An adequate graphical console may require built-in hardware equivalent to that required in a fairly sophisticated computer. This is an area in which analogue as well as digital techniques may be important. It is an area in which the new component technologies may make significant contributions." (Rosen, 1968, p. 1447).

"Design efforts are directed towards realizing a console that uses a cathode-ray tube (CRT) display with approximately 1,800 alphanumeric-character capacity. The data-communication between central computer and console will initially be 200 characters per second with provisions for higher data rates. Several character sets should be possible in addition to the English alphabet. User communications are entered by means of a typewriter keyboard, and special function buttons which designate frequently encountered commands. The user's message is displayed on the CRT prior to the transmission to the time-shared computer, and editing of displayed commands is possible. As the user's conversation with the catalog system progresses, certain data supplied by the computer may be stored locally for future reference, edited as required, and eventually printed in hard-copy form." (Haring, 1968, p. 37).

4.27 "On the hardware side the picture seems to be much brighter, at least in terms of providing color-display systems of greater color fidelity and reliability." (Rosa, 1965, p. 413).

4.28 "Color is deemed a necessary feature because it can reduce errors and increase the assimilation of displayed information." (Mahan, 1968, p. 34).

4.29 "To produce a stereographic display the computer calculates the projected video images of an object, viewed from two separate points. The resulting video maps are stored on separate refresh bands of the rotating memory. The two output signals are connected to separate color guns of a color television monitor, thus creating a superimposed image on the screen. Optical separation is achieved by viewing the image through color filters.

"The display is interactive and can be viewed by a large group of people at the same time." (Ophir et al., 1969, abstract, p. 309).

4.30 "Unsolved problems . . . that derive from the graphic themselves include flicker, ease of use, coupling of programs to do substantive computations, the language of discourse, and the desirability of halftone capability." (Swanson, 1967, pp. 38–39).

"Although the display field has progressed rapidly during the past five years, significant future progress is still required to provide the types of displays necessary to achieve the essential close man-machine interaction at a price that will permit their widespread use. Several major needs and problems facing the display field have been discussed here, including the need for:

(1) better methods of implementing large-screen displays which can provide dynamic real-time operation with both alphanumeric and graphical data
(2) flat panel visual transducers for both large-screen and console displays that:
    (a) can be addressed digitally
    (b) provide storage inherent to the display panel
    (c) are compatible with batch-fabricated electronics and magnetics
(3) better determination of the proper functions to mechanize in the display to facilitate the human interface, including the appropriate human factors determination of the appropriate trade-offs between manual and automatic functions
(4) more effective software both to facilitate the programming of display functions and to provide for the efficient computer generation and control of operations such as the rotation and translation of drawings and the interrogation of large data bases
(5) lower cost for all categories of displays, but particularly for low performance remote display consoles.

Developments or improvements needed in specific display technologies (e.g., the need for higher power or ultra-violet lasers) have also been cited." (Hobbs, 1966, p. 1882).

4.31 "There are . . . areas which I believe deserve priority attention. The first is the development of a small, cheap, convenient desk-top terminal set such as the duffer unit." (Mooers, 1959, p. 38).

"Whereas fast time sharing divides the cost of the computer itself among many users, there is no comparable way to distribute the cost of users' input and output equipment. Therefore the problems of console design and development are critical. Teletype equipment is inexpensive and reliable, but the character ensemble is small, and this seems likely to limit the applicability of teletype seriously. Electric typewriters are more expensive and less reliable, but they provide a reasonably large set of characters (enough, for example, to handle ALGOL with only a few two-stroke characters), and they may be adequate for the input and output requirements of the majority of users. If they are not, then almost surely the next requirement is a drawing board or 'doodle pad' onto which both the operator and the computer can write and make graphs and diagrams. These functions are now instrumented with oscilloscopes; what is needed is a less expensive means." (Licklider, 1964, pp. 124–125).

"Displays are good, but, in the generalized form needed, they tend to be expensive. This means a reduction in physical accessibility, since one does not put a $50,000 or $100,000 box in every office. Displays which are both low-cost and adequate do not exist." (Mills, 1966, p. 197).

4.32 "William N. Locke (MIT) reported briefly on INTREX . . . an MIT Lab is trying to develop a better console because the small consoles are not now very satisfactory." (LC Info. Bull. **25**, 90 (2/10/66).)

"Effective testing of user interaction with the augmented catalog requires a remote computer console optimally suited to the task. Currently available consoles, however, exhibit serious shortcomings as regards catalog experimentation. Impact-printing teletypewriters operating at ten to fifteen characters per second, for example, are clearly too slow for rapid scanning of large quantities of bibliographic data. The cathode-ray-tube (CRT) alphanumeric display terminals now offered by several manufacturers do allow for more rapid, quiet display of computer-stored data. However, they, too, lack features essential to effective user interaction with the augmented catalog. For instance, there is generally a lack of flexibility in operating modes, in formats (e.g., no superscripts and subscripts) and a severe limitation on the size of the character set. On the other hand, the CRT graphic display terminals that are currently available can be programmed to circumvent these deficiencies but are very expensive as regards original cost, communications requirements, and utilization of computer time." (Haring, 1968, pp. 35–36).

4.33 "How much is the end user willing to pay for his terminal? What does he expect for it? What could he do without? The terminal's requirements are obviously going to vary with the application program." (Stotz, 1968, p. 16).

"The need for graphical displays at a large number of terminals remote to the utility places a severe constraint on the allowable cost per display unit." (Dertouzos, 1967, p. 203).

Typically, the R & D requirement is noted for ". . . lower cost for all categories of displays, but particularly for low performance remote display consoles." (Hobbs, 1966, p. 1882).

4.34 "In the multiple-access system environment, point-by-point generation of the display by the main computer results in the imposition of intolerable loads on the processor. The task of simply regenerating a fixed picture, involving no new information, can occupy a major part of processor capacity." (Mills, 1965, p. 239).

"Also, if such high speed consoles are to be used remotely, local display maintenance is essential. Thus, a picture need be transmitted only once, maybe over low-cost low-speed lines." (Ninke, 1965, p. 840).

"There is an increasing trend toward using small satellite computers for local servicing of the immediate demands of the display and the human operators while communicating with a large time-shared computer for complex computations." (Wigington, 1966, p. 88).

"Many modern computers have a memory configuration which can be used to refresh the display without interrupting other computations. Where this is not possible, a buffer memory is available within a display. Commercial terminals use core memories, delay lines, and drums. With the availability of low cost, high-speed, general purpose, digital computers, it becomes feasible to consider including a digital computer in the CRT graphic terminal. BR, DEC, and IDI offer terminals in which the digital computer is an integral part of the display and provides functions of storage, plus some of the hardware mode control features." (Machover, 1967, p. 153).

"There is growing awareness that display buffers should, in fact, be small general purpose computers, which opens up a whole new spectrum of possibilities in properly assigning tasks within the overall system." (Ward, 1967, p. 49).

"The concepts of list processing have proven to be desirable in the manipulation of display data. Second, the hardware and software design of MAGIC . . . provides sufficient local processing abilities to significantly remove the burden of display data processing from the C.P.U. to which it is to be interfaced." (Rippy et al., 1965, p. 829).

"The display material memory is an Ampex RVQ core unit with 4096 36-bit words and a 5 microsecond cycle time. This storage capacity represents about eight large pictures, i.e., those which take about 1/30-th of a second to display." (Ninke, 1965, p. 841).

"The remote operation of displays is facilitated if local storage is provided at the display for refreshing the picture. Thus only changes need be transmitted from the central computer, and the data transmission requirements are greatly reduced. Also, some computing capability can be placed at the display so that change of scale, translation, rotation, and other modest computations can be done locally. In this regard, M.I.T. and others are experimenting with satellite computers which can continuously refresh several displays and perform simple calculations for them, but which call upon a larger computer for extended computation." (Prince, 1966, p. 1706).

4.35 "The Control Edit Console consists of two dark trace storage tubes and associated equipment for control and operation. The dark trace storage tube, and its associated equipment, is a device which will store and display a single frame of video scan for a relatively long period of time (up to several days). It has excellent resolution of up to 500 or more line pairs per inch . . . Through manual control it is possible to erase and edit portions of the display. By using two DTS tubes, it will be possible to duplicate the graphic portions of the original document on the second tube. The display on the first tube will, of course, retain the original document for reference purposes. The selective transfer is accomplished by XY coordinate sliding markers, or by tracing area boundaries with electrostatic or infrared pencil directly on the screen . . ." (Buck et al., 1961, p. VI–21).

4.36 "Bunker-Ramo communications devices lend themselves particularly well to engineering applications. The results of the computations requested by the engineer may be displayed in a meaningful format he is accustomed to seeing—such as a Nyquist plot, or families of plots, for any number of variables." (Dig. Comp. Newsletter 16, No. 4, 37 (1964).)

4.37 "No matter what logic is applied to the management of the data base inside the machine, the surface appearance of the data base must be under the user's on-line control. He should be able to set up the file display, the object and property names, the formats of these files, including sequence and arrangement of data as he desires. He should be able to generate, store and revise the structure of his displays, on-line . . ." (Bennett et al., 1965, p. 436).

For these reasons, it is suggested that "display equipment manufacturers [should] improve and provide software packages that allow:

a. One, two, or three variable-width column page formats with justification routines and masking provisions for inserting graphics.

b. Variable character spacing to improve text density,

c. Variable line spacing to allow text with or without superscripting and subscripting, and
d. Utilization of the software packages on additional general purpose digital computer systems." (Burger, 1964, p. 12).

4.38 For example: "To qualify as standard, a terminal device must operate on-line, use a voice grade channel, provide a visual display, at a rate taxing the reading and scanning speed of the proficient user." (DeParis, 1965, p. 49).

"A reasonable goal is that the console should sell for under $15,000, that it should have a cathode ray tube or something equivalent, that it should allow for some buffering of information, and that it should have a flexible and adaptable keyboard structure and status information display." (Bauer, 1965, p. 23).

"Certainly the design of the user's terminal is important; but far too much emphasis seems to have been placed on high style and novelties to the detriment of dependability and economy." (Adams, 1965, p. 486).

"This terminal equipment should be small. It should be easy to use, since this is to be the main channel of intercommunication between the human worker and the machine system. . . .

"The terminal equipment should provide a typewriter-style keyboard for input, and it should have an alpha-numeric printing device for printing its output. Its output should be printed on paper, either on a paper sheet or on a paper 'ticker tape' with a gummed back. Thus the output can be assembled and edited by scissors and pasting." (Mooers, 1959, p. 10).

"If any of these qualities [good resolution, no flicker, upper and lower case] are badly deficient, the reading becomes so difficult that the type of person required to understand and edit complex information will refuse to use the display." (Buckland, 1963, p. 179).

"To allow a user, however, to do real-time composing, editing, or other manipulation of graphical information with a light pen or other graphical device, the sum of access time and transmission delay must be only a few milliseconds." (Ninke, 1965, p. 840).

"It would seem that an automated system, to be completely satisfactory, has to respond within a few seconds and should present output results at roughly a normal reading rate." (Drew et al., 1966, p. 6).

"The display should have controllable persistence . . . and should be free of flicker." (Licklider, 1965, p. 94).

"Upper and lower case alphabetics should be provided; two symbols should be able to be plotted at the same position on the screen (for underline, circumflex, etc.); and superscripts and subscripts should be possible. Both the computer and the user should be able to set Tabs and their settings should show at a glance." (Stotz, 1968, p. 17).

4.39 "We should like to have: a color display . . . if possible, or, if not, a black-on-white display . . . with at least eight gradations of brightness . . . and a resolution exceeding 400 . . . or 200 . . . or, at any rate, 100 . . . lines per inch." (Licklider, 1965, p. 94).

While eight levels of gray scale may be adequate for many user-oriented remote terminal input-output units (and more is sometimes available), far more is required for sophisticated pictorial data processing.

Ledley's FIDAC (Film Input to Digital Automatic Computer) currently provides only eight gray levels for a 700×500 input spot raster. (Ledley et al., 1966, p. 79).

"Digital Electronics Inc. L–SCAN rapidly converts visual data, such as drawings and objects, into digital format for computer analysis and record storage. It uses a vidicon tube pick-up and records on IBM compatible magnetic tape. The unit can discriminate 64 shades of gray and has a field of view divided into 40,000 segments." (Data Proc. Mag. **7,** 50 (Feb. 1965).)

"Interest is developing in extensions of the display technique to include color and grey scale. It seemed likely from the earliest experiments that the use of phosphors inside the cells could be used in multi-color displays. The later observation of ultra-violet radiation in the cells led to the idea that this radiation could excite phosphors deposited on the outside of the outer glass panels, and that the effect should be enhanced if the panels were made of quartz or some other material with good U V transmission characteristics." (Arora et al., 1967, p. 11).

"The practical application of such displays as chromatron photochromic dyes, coupled with such reproduction means as thermoplastic recording or smoke printing will usher in an era of true electronic printing in all the flexibility we have come to expect in printed communication." (Herbert Ohlman, panel discussion of Markus, 1962, p. 25).

Further, "the National Aeronautics and Space Administration has awarded the Philco Corp., two contracts to develop an experimental color television display system for possible use in the mission control center of the Manned Spacecraft Center in Houston." (Electronics **38,** No. 18, 40 (1965).)

4.40 "Most experienced users want 'terse' modes of expression to the computer and full, unabbreviated (and fast) responses from the computer." (Licklider, 1965, p. 182).

"It should be possible, in a 'debreviation' mode, to type 'clr' on the keyboard and have 'The Council on Library Resources, Inc.' appear on the display." (Licklider, 1965, p. 100).

"Several types of keyboarding shortcuts have been developed; for example, computer programs automatically provide italicized and capitalized characters in chemical names, and the computer also expands useful abbreviations." (Davenport, 1968, p. 37).

4.41 "Each element of the display should be selectively erasable by the computer program, and also directly or indirectly by the operator." (Licklider, 1965, p. 94).

4.42 "DOCUS, developed by Informatics for the multicomputer complex at Rome Air Development Center, provides a display-oriented man-machine system with some built-in data management functions and a capability to assign functions to control keys at the display and define an execute compound functions based on earlier defined tasks." (Minker and Sable, 1967, p. 137).

Other examples viewed generally with favor in the literature include the following:

(1) "Placing control functions on the scope face has two advantages. First, only those controls which should be present at a particular stage of a problem are displayed. If a light button labeled 'MOVE' is one of those present, a user knows that he *can* move picture parts around. Similarly, if only light buttons in the form of PNP and NPN transistor symbols are displayed, a user knows he *must* select a particular type of transistor at that time. Thus, in effect, a user is steered through a problem. Second, during most operations there is only one center of attention, the scope face, on which a user need concentrate. This allows faster and smoother work on a problem." (Ninke, 1965, p. 845).

(2) "STATPAC, a program for scientific data analysis, allows an experimenter to apply various statistical operations and mathematical transformations to data simply by light-penning a desired operation chosen from a list of operations displayed on the scope." (Baker, 1965, p. 431).

(3) "This [SDC Variable Display] program is intended to assist in the design of tabular displays. It permits a user to sort, delete, insert and exchange rows and columns of information presented in matrix form on a display console. Actions can be taken by both light-pen and teletype input." (Schwartz et al., 1965, p. 30).

(4) "These programs . . . [may lead the operator] by providing information on the next step, by informing him which next console steps are permissible, or by signaling him when a console step has been initiated which is not permissible." (Bauer, 1965, p. 22).

4.43 "The major limiting factor in further improvement in light-pen speed is in the phosphor screen itself, which must be of a persistent type in order to reduce display flicker. . . .

"We have developed a system to detect the electron beam causing the screen light rather than the light itself . . . [as a] new approach to increasing the speed of the CRT display system for man-machine communication. . . .

"From experimental evidence we conclude that it is possible to make a system to detect when and where the electron beam of a CRT strikes the screen, thus essentially eliminating the bandwidth-limiting effects of the CRT phosphor and making a high-speed man-machine communications system possible." (Haring, 1965, pp. 848, 854).

"Current development work on CRT's is concentrated heavily in the search for new phosphors to provide increased brightness and longer life." (Mahan, 1968, p. 19).

"Both electroflors [liquid phase materials that fluoresce or change color when small electric currents are passed] and piezoelectric displays show promise, but are hardly beyond the feasibility state of development. Current research spending is not very heavy for these displays so few results are expected in the near future." (Mahan, 1968, p. 28).

4.44 "The use of analog predictive circuitry should be explored as a possible means of improving tracking performance. The simple noise filter in the present experimental circuit serves to provide velocity prediction in the sense that the voltage on the filter capacitor is the average of past error voltages. If an error signal should fail to be developed over several cycles, the voltage on this capacitor would provide tracking continuity." (Stratton, 1966, p. 61).

"The merit of the analog technique lies in the small processing time required to determine the position of the moving pen. Decreasing the tracking interval allows more time to be utilized for display—a particularly important consideration when many consoles share the same display channel." (Stratton, 1966, p. 58).

4.45 ". . . The computer may be operated in a multisequenced fashion . . . One sequence may be used to calculate a file of point coordinates for display and a higher priority sequence may be used to display these points. In this manner, the high priority display sequence insures that points are displayed as often as possible so that the picture does not flicker objectionably as a result of the computation of new points usurping display time." (Loomis, 1960, p. 2).

4.46 "Research and development work on several display technologies offer promise for improved real-time large screen displays by the early 1970's. These include.

Photochromic displays with cathode-ray-tube or laser image generation
Thermoplastic and photoplastic light valves with cathode-ray-tube or laser-image generation
Crossed-grid electroluminescent displays with integrated storage
Laser inscribing systems
Solid-state light valves
Opto-magnetic displays

Electro-chemical displays

Injection electroluminescence matrix displays." (Hobbs, 1966, p. 42).

4.47 "Large-screen displays are used where it is necessary for a group of people to view the same information simultaneously. Because of the cost involved in implementing large-screen displays, their use has been confined largely to military systems. The high cost plus the lack of really adequate technologies for presenting dynamic information on a large screen have seriously restricted the use of group displays. Significant technological improvements are necessary to permit satisfactory group displays at a reasonable price before their utilization will become widespread in the commercial world. Most group displays that have been installed to date involved projection systems of one type or another with the display generated in one device and then projected onto a screen. However, work is underway on several technologies that will permit the generation of the visual image in the screen itself. Some of these are considered later in the discussion of display technologies. Most of the research and development on the visual transducer portion of display systems is devoted to techniques applicable to large-screen displays because of the lack of suitable means for implementing displays of this type at present. The CRT enjoys a dominant position in console displays, but there is no equivalent dominant technology for large-screen displays." (Hobbs, 1966, pp. 1871–1872).

"While large scale display techniques have advanced considerably in the past few years, there is still much room for improvement. Their capability to handle dynamic data needs considerable expansion. Cost which is now high must be lowered and reliability needs improvements. . . .

"Toward this end, considerable research is now underway to improve existing techniques. New films which do not need wet chemicals are being explored along with novel methods of processing conventional films. Considerable effort is under way to improve the performance of the light valve technology. Also, new and better techniques are being developed to convert digital data to the analog form necessary for the exploitation of TV type devices." (Kesselman, 1967, p. 167).

4.48 "When data phones are used in the communication link, experience with existing display systems indicates that several data phones are required to handle many user consoles from a single buffer/controller. Data phones now available for switched telephone networks provide approximately 2000 bits per second of data, but within the near future this rate may be approximately doubled, according to information received from the telephone company. Since one CRT frame contains approximately 20,000 bits, at least ten seconds is required to transmit a complete single frame. Fortunately, the majority of the messages between the user and the time-shared computer will be on the order of one line of text requiring only one-third of a second. However, since a single user might wish to request up to five frames at a time, a maximum of 50 seconds might be required to serve a single user. In order to avoid prolonged delays in service to other users who may be awaiting service at that instant, one 2000-bps data phone must be dedicated to a small number of consoles, or the servicing of the consoles must be interlaced, or combinations of these two must be employed. At the present time, our thinking runs toward use of one data phone for every three consoles, and interlacing the service to provide response time of less than 30 seconds under worst-case conditions. Since, in actual practice, users most frequently will be sending and receiving much less than a complete frame and furthermore, since the probability that several users will be communicating data simultaneously is very small, as regards the communications delays, the service would typically be less than a second." (Haring, 1968, pp. 38–39).

"The video buffer contains the necessary electronics for head selection, writing, and sync mixing. Each head is in a read (or display) mode except when writing, and a single write driver serves all the heads." (Terlet, 1967, p. 172).

Roberts suggests that "it is possible . . . to time-share one vector-curve generator for several display units if the generator is fast enough to eliminate excessive flicker. Each display then receives the common deflection signals, but is only intensified when the segments being drawn are intended for that unit. This technique allows the generator cost to be shared by up to four displays at present speeds." (1965, p. 217).

"In order to reduce the cost of individual consoles, it is advantageous to cluster consoles around a local station which includes data storage and processing that is common to all clustered consoles. Initial investigations indicate that it should be possible to design economical console systems which cluster about ten consoles at distances of a thousand feet from a local station. Thus, the consoles could be placed in several different rooms of a single building. Interconnections between the consoles and the station are made with coaxial cables, while the connection between the station and the time-shared computer utility are made by common carrier. In the future, a high-speed photographic printer will be located in the vicinity of the console to produce hard copy on command from any of the consoles." (Haring, 1968, p. 258).

4.49 "Human factors, habit patterns, etc., have to be considered with respect to both operation of the terminal and designing new procedures." (Duffy and Timberlake, 1966, p. 273).

"We have planned a survey of man-machine relationships, both at present and with contemplated systems, from two points of view: (1) man-machine relationships from the standpoint of human engineering principles, and (2) the relationships from the standpoint of the attitudes of the people who will be operating the system." (Sharp and McNulty, 1964, p. 2).

"Heretofore not much has been said about the mechanical design features of the consoles. A great deal of design effort is being applied to the human engineering aspects of the consoles since it is imperative that the user's initial contact with the consoles, the only part of the Intrex experimental library which the average user sees, be a pleasant one. The objectives here are to retain sufficient flexibility in the initial consoles to permit effective user evaluation of various features and options while at the same time to maintain a finished look to the consoles." (Haring, 1968, pp. 263–264).

"Human errors and the education of human beings are, therefore, two systems design factors which must receive significant attention. The systems designer must understand the chief motivations of the terminal operators. Wherever possible, he must design into the system factors which will lead to operator satisfaction as a result of successful operation of a terminal. Operator education, both at the start and on a continuing basis, must also be carefully planned. This is particularly true for systems which may expect a significant turn-over in terminal operators within a relatively short period (e.g., 6 months to a year) after the initial implementation of the system. Operator education must be recognized as a continuing system function. Wherever possible, means for providing education or guidance for operators should be designed into the terminal device or the system as a whole.

"The efficiency of the terminals and the system, and the degree of intrusion introduced by the system into the regular jobs or occupations of the terminal operators, also must be considered. Many people in the organization will assume a second role as a result of the information system. In addition to their regular job, they will now also be expected to act as a recorder of data. As a result, human factors will be extremely important in the design of terminal devices. This will insure that the data recording operation is as simple and straightforward as possible, and requires a minimum effort from the terminal operator." (Pedler, 1969, p. 30).

4.50 " 'Interface', with its connotation of a mere surface, a plane of separation between the man and the machine, focuses attention on the caps of the typewriter keys, the screen of the cathode-ray tube, and the console light that wink and flicker, but not on the human operator's repertory of skilled reactions and not on the input-output programs of the computer. The crucial regions for research and development seem to lie on both sides of the literal interface." (Licklider, 1965, p. 92).

4.51 "The 'process' keys would be used to institute queries to specific portions of the automated catalog and to respond to the next steps suggested by the automated system. At least a 120-character or symbol set would be desirable, in contrast with the 64 characters typically available now. This means that effort will have to be placed on new or improved and certainly more economical means of character generation." (King, 1963, p. 19).

"Several basic hypotheses resulted from the study program and have been used in the formulation of the initial design concepts. First, it is advantageous to handle many routine operations at the console in order to minimize communication between the console and the time-shared computer. This approach reduces the demands on the central computer and should result in more rapid access to the central machine when required. It further reduces the cost of transmitting information from the time-shared computer to the console, an important consideration in any large operational system. Second, careful attention should be given to the size and content of the console alphabet, the ability to produce superscripts and subscripts, and to the human engineering aspects of the console in order to ensure favorable user reaction to the console and to the overall system. Third, it must be possible for the uninitated user to become familiar with the operation of the console and the catalog system rapidly and easily. Finally, the design of the console should be such that it can be economically reproduced. This feature is a necessary prerequisite to the wide-scale user of computer-based library systems." (Haring, 1968, pp. 257–258).

4.52 "Careful planning of systems outputs may permit the complete specification of all files to be maintained and the input entering such files. Let us examine input first. The systems designer must be concerned with content. All needed data to be printed in reports must first be entered into the computer. In addition to this substantive data, the designer must also consider any necessary control data which must be part of the input to the computer. For example, if the system is to use sophisticated photocomposition equipment with an expanded character set, then typographic symbols must be included in the computer input. For example, upper and lower case indicators must be entered, variations in sizes of type to be used on the composer, indications of which characters are to be printed in bold face, which are to be printed in italics, etc. . . .

"The character set to be employed in a system is an obvious important factor in systems design. The designer must consider how sophisticated a character set is required. He must decide whether on the basis of the user's requirements upper and lower case characters are needed, whether different sizes of type would be useful in preparing publications, whether the Latin alphabet is adequate or whether Cyrillic characters must be provided. He must also determine the requirements for special characters such as diacritical marks required for certain foreign languages or subscripts and superscripts needed for chemical notations." (Austin, 1966, pp. 243–244, 245).

4.53 "In a comprehensive chemical data processing system there is a real need to input and output conventional molecular or empirical formulae, various nomenclatures, structure formula diagrams, and considerable generic information and data. To accomplish the output function, the system analyst was, until recently, limited in his choice of output hardware. This restraint led to the use of numerous and often cumbersome coding techniques and printing conventions which must very often be learned by the chemists themselves." (Burger, 1964, p. 1).

"Examples of elaborate code conventions adopted for keypunching of text include reports by Nugent (1959) and by Ray (1962), both of which point out some of the requirements and some of the difficulties encountered with respect to providing a manual for the keypunching of natural language texts. An even more sophisticated encoding-transliteration scheme is detailed by Newman, Knowlton and Swanson (1960) as necessary for the keypuching of patent disclosures in which a very wide variety of boldface, normal, italic faces and of special symbol insertions must be provided for. . . .

"Flexible selection from amongst a large variety of available characters and symbols may thus be provided for, but at the high expense of multiple initial keystroking, multiple code-sequence processing and redundant storage requirements for each 'actual' character eventually to be reproduced. For example, with respect to the early Barnett experiments using Photon, it is claimed that the proportion of control and precedence coding to actual character-selection identifications could run as high as 75 percent of the total input. While possibilities for re-design of keyboards and for multiple-output from a single key depression may alleviate this problem somewhat, the difficulties of precedence coding to achieve larger and more versatile character sets remain a major problem area." (Stevens and Little, 1967, p. 75).

"As an output device . . . the painfully slow printing rate [of the teletypewriter] impedes all but the dullest of men. Its limited symbol set, and its rigid format for placing characters on a page, makes its display of information very minimal. Graphs come out as x's on a page, giving only the coarsest possible feel for the information. Mathematical expressions must be coded in such a complicated shorthand that only the program's author can interpret it without a guidebook." (Stotz, 1968, p. 13).

4.54 ". . . Special provision for 64 program keyboard overlays, each of which, when inserted, changes both the labels and the functions associated with the keyboard buttons. A newly inserted overlay links the buttons with different sets of computer programs and so completely reorients the use of the console." (Dig. Comp. Newsletter **16**, No. 4, 35–36 (1964).)

4.55 Thus: "The greatest promise for future development seems to be in increasing input flexibility of user terminals . . . We are beginning to see the use of parallel-key devices, based on the stenotype principle . . ." (Ohlman, 1963, p. 194).

"If a data file is extremely redundant (such as a natural-language text) then the stenotyping technique cuts the number of keystrokes required by as much as two-thirds." (Partick and Black, 1964, p. 43).

"The automatic conversion of stenotyping is being actively pursued with the aim of reducing the cost of file conversion." (King, 1963, p. 9).

". . . The central problem of keyboard design is to get a large selection of codes from a limited, properly spaced, simple-to-operate arrangement of keys." ("The (R)evolution in Book Composition . . . IV," 1964, p. 68).

"It may be that we shall have to wait for more fundamental research to clear the way for a chord typewriter, played more like a piano." (Duncan, 1966, p. 264).

"If it turns out, as seems likely, that very large ensembles of characters are desirable in man-computer interaction with the body of knowledge, then it will become much more important that it is now to be able to specify the desired character by pressing a pattern of keys on a small keyboard. That is a much better solution than pressing a single key on a keyboard with several thousand keys." (Licklider, 1965, p. 100).

4.56 The case of chemical information is even more demanding: "It is difficult to devise an algorithm that allows the sorting process to ignore characters that should be ignored in traditional alphabetization of chemicals. For instance, 1,3-dimethyl is alphabetized under M, dimethylaminopropyl under D, and 1,3-bis(dimethylaminopropyl) under B. Using a flexible listing order that can be specified for the index solves the ordering problem in this system; editorial work is, of course, a consequence. The advantage of flexibility in the face of a difficult problem was considered sufficient justification for this effort." (Tinker, 1968, p. 324).

4.57 Problems of character-set repertoire are particularly acute in the areas of primary publication of scientific and technical texts, bibliographies (e.g., in the Besterman *World Bibliography of Bibliographies*, 1950 different pieces of Monotype characters were used) (Shaw, 1962, p. 268) and in library card catalogs.

Ohringer comments: "There will be many formulas and special mathematical symbols interspersed with the text. The type fonts used tend to vary greatly, including many Greek letters in addition to many styles and sizes of Roman alphabet. The page arrangement also contains too much variation for present-day optical character readers." (1964, p. 311).

4.58 "A character set for instruction must often include a far larger number of characters and symbols than is needed for other applications. For example, teaching a foreign language may require that two different alphabets be displayed at once. In mathematics, a display must often include exponents, subscripts, and fraction lines, as well as alphanumeric characters and mathematical symbols." (Terlet, 1967, pp. 169–170).

"Primarily because of the complex chemical names, chemical information publishing demands the use of the Roman and Greek alphabets, upper and lower case letters, several type fonts (italics, boldface, small capital letters), and superior and inferior positions. In all, nearly 1500 symbols are used in *CA* issues." (Davenport, 1968, p. 37).

4.59 "The data contained in the augmented catalog are basically alphanumeric. Of particular consequence to both the display console design and the entire computer-based library is the large number of alphanumeric symbols that is required. The set of 128 USASCII standard symbols is insufficient, and thus must be augmented. Furthermore, provisions for superscripts, subscripts and underlines must be included to properly display to users in forms with which they are familiar such items as chemical formulas and mathematical equations." (Haring, 1968, p. 36).

4.60 "Filing rules pose a particularly complex problem to the designer of an information system. Unfortunately, the machine has not been built which will sort according to such filing rules as those laid down by the American Library Association. The system designer must choose between an attempt to program these rules into the computer or to employ special control codes on input to permit the citations to be sorted according to the filing rules rather than the normal collating sequence of the computer." (Austin, 1966, p. 244).

4.61 "The earlier work of Opler and Baird in drawing chemical structure diagrams on a computer controlled CRT gave much promise for the future applicability of such devices. . . .

"Use of 2-case print mechanisms on high-speed computer printers for the display of extended chemical character sets has been under joint development by IBM and Chemical Abstracts . . ." (Burger, 1964, p. 2).

"The use of photocomposition equipment to reproduce structural chemical formulas from coded tape is of special interest in the publication of the output of chemists and chemical engineers, but the proposed work would have application to almost all other branches of science where publication of material requiring spatial delineation is necessary." (Kuney, 1963, p. 249).

"Using as a starting point the characters developed by workers at American Cyanamid for the typing of chemical structures, we proposed a font of 50 lines and angles with which we could construct the needed bonds and rings.

"Machine setting of chemical structures was suggested as one of the potentials of the photocomposition work we started in 1958. The development of the chemical typewriter by Jacobus and Feldman at Walter Reed and computerized typesetting techniques by Barnett and others stimulated the development of a test matrix disc for the Photon." (Kuney and Lazorchak, 1964, p. 303).

"With the cooperation of the workers at Walter Reed, we are planning to encode structures using the Army chemical typewriter and process this input via computer to get a tape which will operate the Photon for the setting of chemical structures." (Kuney and Lazorchak, 1964, p. 305).

4.62 "The ultimate challenge to calligraphy for computers is the imitation of brush strokes in Chinese and Japanese characters. An investigation has been made to determine the feasibility of digitalization of the Japanese characters. The results . . . have been used for the preparation of an abstract of a Naval Weapons Laboratory report in Japanese as well as in French and German." (Hershey, 1967, p. 15).

4.63 "An application of the GDP, dubbed 'Type-A-Circuit', has been developed by L. Mailloux and his colleagues. A contrived alphabet or character set may be assembled into a pattern to create a mask for printed circuit etching. Horizontal, vertical, and diagonal segments, bends, mounting pads, and sockets or transistors and several types of integrated circuits have been made a part of this character set . . .

"The processing program also contains plugboard prongs which are superimposed over the image generated by the Type-A-Circuit specifications. In use, the designer prepares the string of 'letters' which specify the elements of the Type-A-Circuit character set in juxtaposition with one another, thus forming leads, bends, pads, and sockets. This specification is prepared with the aid of a rough sketch drawn on a specially prepared form. The graphical output consists of a finished negative which may be used directly for photoetching of a copper clad board. The time required to prepare artwork for etched circuit boards has been greatly reduced with the Type-A-Circuit system." (Potter and Axelrod, 1968, p. 4).

5. Programming Problems and Languages and Processor Design Considerations

5.1 "The most important need is for a design philosophy that aims at the design of total information processing systems, and that will eliminate the mostly artificial distinction between hardware systems and software systems. We need a continuing development of the trend toward combined hardware-software programming." (Rosen, 1968, p. 1446).

"Since, ultimately, the only computer system of any significance to the outside world is the system composed of hardware plus software, one cannot claim to have truly designed a computer system without having designed both . . . 'Integrated Hardware/Software Design' requires not only a knowledge of hardware design and program design, but a thorough understanding of the total relationships between hardware and software in a working system. Effective hardware/software design means consideration of the many potential tradeoffs between capability resident in the machine configuration and capability resident in the supporting software." (Constantine, 1968, p. 50).

5.2 For example, at the [ACM–SUNY Conf.], "Dr. McCann talked about the need for 'Language Escalation'" (Commun. ACM **9**, 645 (1966)), while Perlis (1965), Clippinger (1965), and Burkhardt (1965), among others, discuss the general problems of hierarchies of language.

5.3 "*Very large programs*, roughly defined, are those that (1) demand many times the available primary storage for retention of code and immanent data, and (2) are sufficiently complex structurally to require more than ten coders for implementation." (Steel, 1965, p. 231).

"For the hypothetical air traffic control system used as an example, approximately forty *volumes* of several hundred pages each would be necessary to specify the program subsystems fully. In addition to detailing the many functions that must be performed by the several programs, limits on environmental behavior and transfer functions between the environment and the communication network must be described . . . The amount of interrelated, precise and not easily obtainable data required is staggering." (Steel, 1965, p. 233).

"The point upon which the mind should focus in the foregoing description of current large-scale programming procedures is that many people work a long time to prepare a computer to do quickly what it would take many people a long time to do. The number of people involved in a large programming task is very great, and the time it takes to prepare the program successfully is very long. For example, the programming of the entire Semi-Automatic Ground Environment system took roughly a thousand man-years, and the average output for the entire staff was between one and ten 'debugged' and final machine instructions per day. Despite the fact that almost any programmer can write a valid subroutine of ten instructions in ten minutes, the figure for the Semi-Automatic Ground Environment system does not indicate that anyone was lazy or inept. It represents the extreme difficulty of very-large-scale programming and the essential incoherence, insofar as complex and highly interactive procedures are concerned, of large, hierarchical staffs of people." (Licklider, 1964, p. 121).

5.4 How can very large, very complex, problems be effectively segmented for programmer attack?

"For the practical application of programming languages to large problems, efficient segmentation features are desirable so that parts of problems can be handled independently." (Burkhardt, 1965, p. 5).

"Automatic segmenting of code is a critical and difficult problem. To be efficient, a program should not loop from segment to segment and further, all code not normally executed should be separate from the main flow of the program. Since program segments will be retrieved on demand, this reduces the program accesses." (Perry, 1965, p. 247).

"Since running programs will have access to only a portion of the memory, frequent 'page turning' will be necessary as the program goes through its major operating pieces. Segmenting of the program can be very difficult if it must be done manually by the programmer. Assemblers or compilers with automatic segmentation or semi-automatic segmentation are needed." (Bauer, 1965, p. 23).

5.5 "We must now master, organize, systematize and document a whole new body of technical experience—that pertaining to programming systems." (Brooks, 1965, p. 88).

"When a programmer is asked to change a record format, for example, in an unfamiliar program, or when a systems analyst must estimate the time required for such a change, difficulties may arise which are out of proportion to the routine nature of the problem . . .

"Inadequate documentation may be regarded as one of the most serious problems confronting computer users." (Fisher, 1966, p. 26).

"One major concern is the program library. There are many needs here. One is an indexing system to permit users to retrieve a program from among the many. Another is adequate documentation of library programs. Documentation must specify what the program will do and under what conditions. Still another need is a linking mechanism: That is, a means for passing data from one library program to another without manual intervention so that library programs can become segments of composite, larger programs. These requirements make it difficult today to provide a convenient library of computer processes even in a single computer, not to mention the problems raised by machine-to-machine incompatibility. Today it is difficult to stand on the shoulders of previous programmers." (David, 1966, p. 2).

"The importance of a library to provide a repository for programs was recognized early, but full exploitation has been impeded by poor program documentation, lack of interest on the part of programmers, and language problems. Many program libraries now consist of programs in languages either dead or destined for an early demise. Limitations result from the dearth of program 'readers' and the serious practical difficulties in translation between machine languages." (Barton, 1963, p. 170).

5.6 "One of the most significant elements in the orderly, rapid assimilation of multiaccess system technology is adequate and appropriate documentation. 'Appropriate' is the operative word here, since the historical norms for system and program documentation are probably inappropriate for the future. The time is rapidly approaching when 'professional' programmers will be among the least numerous and least significant system users." (Mills, 1967, p. 227).

5.7 "However, there is another means of reducing programming cost—making use of program development already done by others. At present this is difficult to do because of poor documentation and maintenance of programs by their authors. The primary reason for this sad state of affairs is the absence of any clear incentive for program authors to provide good documentation and to tailor their programs to the demands of prospective users rather than their own private whims." (Dennis, 1968, p. 376).

5.8 "The importance of documentation in the management of large programming developments is generally accepted. A number of groups have found a formal system of documentation the most effective management tool at their disposal. In its most advanced implementation, such a system of documentation is on-line to a time sharing system available to all participating members of the system programming project.

"Difficulties often are related to the programmer's resistance to documentation which may be due to several reasons:

- Lack of tangible evidence of benefit to his own activity.
- The inaccessibility of his colleagues' documentation because of sheer quantity, lack of organization and common format and out of date status.
- Rejection of standards, imposed for reasons he does not appreciate.
- Belief (often confirmed) that he can get along without, and in fact feel at his creative 'best' when free to improvise.

"Putting a documentation system on-line appears to have overcome this resistance in a manner acceptable to the programmer.

- The system itself can help him by rejecting certain types of inconsistencies.
- He has instant access to the latest version of his colleagues' work.
- Standards have been translated into formatting conventions with which he is familiar.
- He understands that the system must safeguard itself and his programs from unauthorized change. Thus, he more readily accepts the need for authorization to change and implement." (Kay, 1969, p. 431).

5.9 "The greatest difficulty in programming still concerns the language to be used and the fact that any given program is relatively non-interchangeable on another machine unless it has been rather wastefully written in, say ALGOL or FORTRAN." (Duncan, 1967, p. x).

Machine language translation programs are therefore of interest, since they allow programs written for one machine to be run on another and they provide a bootstrap for changeovers from one equipment system to another. Examples of such programs are Control Data's computer-aided translation system to transfer 7090 programs into their own 3600 Compass language (Wilson and Moss, 1965) and a system developed to reprogram Philco 2000 codes into IBM 7094 language (Olsen, 1965).

5.10 For example, "Any software system would become increasingly useful if it could be adapted to a variety of I/O configurations." (Salton, 1966, p. 209).

"If the performance of input/output functions requires specialized coding in the master control program of a system, then altering the set of peripherals or changing its *i/o* functions requires modifications of the master control programs, leading to the . . . problem of coping with evolution." (Dennis and Glaser, 1965, p. 9).

"If systems design can be automated, i.e., programmed for a computer, ultimately the configuration can be selected by systematically designing the systems for a variety of configurations and selecting the configuration which will run these applications at lowest cost." (Greenberger, 1965, p. 278).

5.11 "Several apparently mutually exclusive features of programming languages all have their advantages . . . How are we to resolve these issues?" (Raphael, 1966, p. 71).

5.12 "Walter F. Bauer, president of Informatics Incorporated, . . . predicted that in ten years all computer systems will be online systems and that 90 percent of all work on computers will involve online interaction." (Commun. ACM **9**, No. 8, 645 (Aug. 1966).)

5.13 "*Multiprogramming:* That operation of a (serial) processor which permits the execution of a number of programs in such a way that none of the programs need be completed before another is started or continued." (Collila, 1966, p. 51.)

"A subfield of multiprogramming is concerned with the problems of computer system organization which arise specifically because of the multiplicity of input-output devices which interface with the system. The problems in this area are referred to as problems of multiaccessing." (Wegner, 1967, p. 135.)

"The requirements for console languages will pose a formidable problem for facility designers of the future." (Wagner and Granholm, 1965, p. 287).

"The whole system is multi-programmed, there being a number of object programs in core at once. Undoubtedly, we shall see such systems in operation and undoubtedly they will work. In the present state of knowledge, however, the construction of a supervisor for such a system is an immense task, and when constructed it has severe run-time overheads." (Wilkes and Needham, 1968, p. 315).

5.14 Brooks says further, "the new systems concepts of today and tomorrow are most keenly *programming systems* concepts: efficient time-sharing, fail-softly multiprocessing, effective mass information retrieval, algorithms for storage allocation, nationwide real-time Teleprocessing systems." (1965, p. 90).

5.15 "Most individuals accustomed to scientific computation or commercial data processing fail to appreciate the magnitude of the programming effort required for real-time control system implementation." (Steel, 1965, p. 231).

"Dr. Saul Rosen of Purdue University mentioned several fallacies of current time-sharing systems of which the most important is the belief that manufacturers who have great difficulty producing relatively simple software systems will somehow be better able to produce the very complex systems required for time sharing." (Commun. ACM **9**, No. 8, 645 (Aug. 1966).)

5.16 "Typical functions of such executive systems include: priority scheduling, interrupt handling, error recovery, communications switching and the important and relevant area of cataloging, accessing and manipulating information and program files." (Weissman, 1967, p. 30).

5.17 "Today's fastest machine cannot be loaded down and will be idle most of the time unless it is coupled to a large number of high speed channels and peripheral units . . . In order to distribute input-output requests in a balanced flow, it must also be controlled by a complex monitor that chooses wisely among the jobs in its job queue." (Clippinger, 1965, p. 207).

"In some systems, more than one single program is processed with simultaneity . . . Inefficiency often results because the mix of individual programs, each written for sole occupancy of a computer, is unlikely to demand equal loading of each parallel element." (Opler, 1965, p. 306).

"System overhead includes scheduling and the continuous processing of console input. These functions are almost uniformly distributed, degrading the processor's execution rate by almost a constant." (Scherr, 1965, p. 14).

"The executive is usually multipurpose. It must be designed with a balance between the conflicting requirements of (1) continuous flow or batch processing, and (2) control for a demand processor in case time-sharing consoles should be attached. In addition, it usually has facilities for on-line control—in particular for communications switching." (Wagner and Granholm, 1965, p. 287).

"The utility programs provide three basic functions: the movement of data within the system required by time sharing or pooled procedure, the controlling of the printout of information on a pooled basis, and the controlling of accesses to auxiliary memory." (Bauer, 1965, p. 22).

"From the system designers' point of view, in time-sharing systems the most important thing is the supervisory program. Gallenson & Weissman pursue this subject in considerable detail and highlight other features such as 'memory protection, error checking circuitry for hardware, software and operator error checks, an interrupt system . . . reliable logical modules [and] dynamic relocation mechanism' as being essential for time-sharing." (Davis, 1966, p. 225).

"From a programmer's point of view, one of the most important features of the second generation of computers is the way it is possible to exploit their automatic interruption facilities to provide control programs and operating systems. A typical computer will have stored in it, more or less permanently, a control program (which may be called the 'Director', 'Master', 'Supervisor', 'Executive', etc.) whose functions are usually to arrange the loading and unloading of independent 'object' programs (the programs which actually do the work) and keep a record of the sequence of jobs they perform, to allocate input-output devices to these programs, and to enable the computer's operators to exercise the necessary control over its operation. It may also provide facilities for performing various kinds of input-output operation. The control program may be able to arrange for several object programs to be stored in the computer at once, and to 'time-share' the use of the instruction-sequencing unit of the computer between all these programs. . . .

"The relationship between a control program and the object programs it controls in many ways resembles that between a deity and mere mortals—the analogy extends to the permanence, privileges, independence and 'infallability' of control programs. Perhaps because of this, a misconception seems to have grown up about the extent of their activities. Although in a computer equipped with one instruction-sequencing unit the control program only 'comes to life' following an interruption of the object program, and effectively expires when the latter is resumed, it seems to be half-believed that, all the time the object program is active, the control program is leading some kind of independent existence; like an all-seeing presence, keeping a close watch on all the activities of the object program. This myth probably springs from experience of the behaviour of the control program when the object program is caught obeying an illegal instruction: but in fact this occurrence is detected by hardware, not by the control program itself." (Wetherfield, 1966, p. 161).

"Built-in accounting and analysis of system logs are used to provide a history of system performance as well as establish a basis for charging users." (Estrin et al., 1967, p. 645).

5.18 "A very significant development in software and one which must be given serious attention by the facility system designer, is the relatively new concept of *Data Base Management*." (Wagner and Granholm, 1965, p. 287).

"The layout and structuring of files to facilitate the efficient use of a common data base for a wide range of purposes requires careful analyses of the applications, the devices which store the files, and the file organization and processing. The criteria for efficiency are, as usual, maximum throughput and minimum requirement for storage space. Ease of programming, program size, and running time are also important considerations." (Bonn, 1966, p. 1866).

"The most widespread information retrieval systems are those for *data base file management*, which process records organized into fields, each containing a type of data in the record." (Hayes, 1968, p. 23).

"Data Management Problems. It is interesting to review a few of the problems raised by G. H. Dobbs at the summary session of the first symposium on data management systems mentioned above. One of these was the diverse terminology and points of view, which make it difficult to extract any basic principles. Another was lack of concern to input quality control. Still another was lack of appreciation for the real-life data base problems as the user sees them. At the second symposium, two years later, Galentine described the relative lack of progress as 'apalling.' Dobbs, at this second session, identified several specific technical areas needing further development—among these, the ability to allow an unsophisticated user to describe data structures, capability to change data and file organization, ability to share files among simultaneous users with adequate file security 'lockout' procedures, and the need for more flexible report formatting." (Climenson, 1966, p. 128).

5.19 One example of a developmental system claiming to incorporate these features is the Catalog Input/Output System at RAND Corporation. More specifically: "Computer applications in linguistics, library science, and social science are creating a need for very large, intricately structured, and in some cases tentatively organized files of data. The catalog—a generalized format for data structures—is designed to meet that need . . . The computer programs will:

a) Facilitate partitioning, rearranging, and converting data from any source in preparation for writing the catalog.
b) Format and convert data for printing on one of a variety of printers.
c) Sort the data elements within a catalog and merge data from two or more separate catalogs.
d) Restructure a file by rearranging the order of classes of data—catalog transformations.
e) Address nodes in the structure, retrieve data from the structure, and add to or delete from the structure—file maintenance." (Kay et al., 1966, pp. 1–2).

5.20 "In recent years there has been a rapid growth in the use of so-called 'formatted file systems'. These systems are general-purpose data storage, maintenance and retrieval systems designed to provide the user with a maximum amount of flexibility. They feature the use of a single set of programs to handle a variety of demands on a group of large files. Each file may possess a different format, but all records within a file must be identical in format. New files may be created or old files changed to meet new requirements. Data can be added to files, or changes can be made to correct errors in existing files." (Baker and Triest, 1966, p. 5–1).

"The Formatted File System (FFS) developed for the Defense Intelligence Agency is a general-purpose data management system for the IBM 1410 which is coupled to the 1410/7010 Operating System. It is oriented to a set of users (technicians) who can maintain an intimate knowledge of the structure of their files and the query language to access them. It employs both tapes and disc to define, maintain, and query a set of independent files. A table of contents and cross index can be defined and maintained on tape or disc. An FFS file must have a unique key field group in each record. A single level of embedded files (periodic sets) is permitted in the record. Except for the last field of a record, all fields are fixed in length. The query language permits general logical conditions and relations and provides several geographical and statistical operators. FFS is one of the few general-purpose data management systems which are operational." (Minker and Sable, 1967, p. 148).

"The users of non-numeric systems had requirements for very long alphanumeric records. Some of the records were formatted as were unit records but the fields were not all of predetermined length. To cope with this, the formatted file concept was developed. It had the ability to handle records of variable length by referring to a data definition which described the permissible record contents, context, and internal structure. The data definition could be carried within each record but was more normally separated into a data definition table to eliminate redundant entries. The formatted file could handle variable length records but could not interpret completely free form text. Special techniques were developed to handle free text which, in general, relied on the usual delimiters in the text, such as periods and commas, to identify the end of each structural unit. Free text then could be interpreted by scanning it as though the computer were reading it from left to right." (Aron, 1968, p. 7).

5.21 "Univac's B–O or Flow-Matic, which was running in 1956, was probably the first true Data-Processing compiler. It introduced the idea of file descriptions, consisting of detailed record and item descriptions, separate from the description of program procedures. It also introduced the idea of using the English language as a programming language." (Rosen, 1964, p. 8).

5.22 "General Electric has announced GECOS III (General Comprehensive Operating Supervisor III), an advanced operating system for large-scale computers. GECOS III integrates requirements for on-line batch, remote batch, and time-sharing into one system using a common data base. The 'heart' of the GECOS III is a centralized file system of hierarchical, tree-structured design which provides multiprocessor access to a common data base, full file protection, and access control." (Commun. ACM **11**, 71 (Jan. 1968).)

5.23 "The Integrated Data Store (IDS), developed by Bachman of the General Electric Company, is a data processing programming system that relies on linkage of all types for its retrieval and maintenance strategies. Through extensions to the COBOL language and compiler, IDS permits the programmer to use mass random-access storage as an extension of memory." (Minker and Sable, 1967, p. 126).

"The IDS file structure allows a linked-list structure in which the last item on every list is linked back to the parent item that started the list. Thus, it is possible to return to the parent item without a recursive list of return points. In IDS, each record is an element in a linked list. A file of records may be subordinated to a master record by linking it to the first member of the subordinate file and chaining from that point, through each record in the subordinate file, through the last one, and back to the master record. There is no inherent limit in IDS to the number of records that may exist in a chain or to the number of detailed chains that may be linked to a given record with a single master record. There is also no inherent limit to the depth of nesting that is permitted; i.e., a record in a chain that is subordinate to a given record may, in turn, have subordinate record chains." (Minker and Sable, 1967, pp. 126–127).

"The G.E. Integrated Data Store is an example of a linked file organization. Master and detail items are organized in a series of linked chains to form records. Each chain at least one master item and one or more detail items. Each item contains linking or chaining information which contains the addresses of the next item and the previous item in the chain. An item may belong to several chains, and linking information to all chains is included in the record." (Bonn, 1966, p. 1867).

5.24 "Franks describes the SDC Time-Shared Data Management System (TDMS), whose design draws upon ADAM and the earlier LUCID. TDMS employs an interesting data structure involving only a single appearance of each item of data with appropriately organized pointers to represent order, multiple instances, etc. This is a much-discussed idea that has needed exploration in a large system. TDMS, like too many similar systems, lacks means by which the system can 'learn' frequently traversed paths through the data, a mechanism that would permit subsequent identical or similar searches to be handled more efficiently." (Mills, 1967, p. 240).

"Williams & Bartram have developed a report generator as part of the TDMS. The object of this program is to give a nonprogrammer the ability, while he is on-line with the system, to access a large file of data for the purpose of describing and generating a report. Another work in this area is by Roberts." (Minker and Sable, 1967, p. 137).

"The file organization of TDMS is an inverted tree structure with self-defining entries. This organization has made it possible for TDMS to meet its goal of providing rapid responses to unpredictable queries in a time-shared environment. Although this organization requires more on-line, random-access storage than most other file organizations, the benefits obtained far outweigh this storage cost." (Bleier and Vorhaus, 1968, p. F97).

5.25 "IBM has developed a Generalized Information System based on experience gained with military file applications. Because of IBM's intention to provide this system as part of its applications library for the System/360 series, this system undoubtedly will be examined quite closely by a variety of potential users. The system has two basic modules: one for defining, maintaining, and retrieving files of 'formatted' data, and one for text processing and concordance-type retrieval." (Climenson, 1966, p. 126).

"The text-processing module of GIS includes three basic files: (1) a dictionary ordered on key word, each record containing: pointers to synonyms and equivalents, key word frequency data, and a pointer to (2) the inverted file, which can contain a variable number of document numbers indexed by the given key word. Finally, (3) the master file can contain bibliographic data and all words stored for that document. Given the document number, the bibliographic data, and key words from the document, the system can automatically generate the above files." (Climenson, 1966, p. 127).

5.26 "GRED, the Generalized Random Extract Device developed at Thiokol Chemical Corporation and described by Heiner & Leishman, is written in COBOL. Files within the system follow the COBOL restrictions of fixed-record size and fixed-field length size for each field; the files are also restricted to tape. File definitions are provided at run time by the user, who specifies the file and record description. A file definition library option is provided and can be maintained by input request. The system, developed for the IBM 7010 computer, has the ability to sort and output data, and is useful for small files." (Minker and Sable, 1967, p. 147).

5.27 "At a second symposium held in September 1965, a benchmark problem was used to organize the discussion of specific systems. The problem involved a management data base—that is, an organization table and personnel files. Five systems were given the same file data and asked to create the file(s) and perform several kinds of operations on it. The five systems were: COLINGO of MITRE Corporation, the Mark III File Management System of Informatics, Inc., the on-line data management system by Bolt, Beranek, and Newman, Inc., the BEST System of National Cash Register, and the

'Integrated Data Store' of General Electric." (Climenson, 1966, p. 125).

5.28 "This work has led to the definition of FILER (File Information Language Executive Routine), the formalization of a calculus of operations with specific relevance to problems of file organization." (Hughes Dynamics, 1964, p. 1.3).

5.29 "Apart from languages at the implementation or procedural level, a number of user-oriented systems employ list-structured data as a basic mechanism. Bernstein & Slojkowski describe a system called Program Management System (PMS), which stores data in a two-level file structure. Associated with each file is a file name, a list of pointers to its subfiles, and a list of pointers to other files." (Minker and Sable, 1967, p. 126).

5.30 "The long-range objectives are:

"1. To define some of the characteristics of large files, and to develop the structure for a large file of heterogeneous scientific and technical information including chemical structure representations, with particular attention to the necessity for:
   a. Manipulating information which is in some cases formatted and in others completely amorphous.
   b. Making provision for inclusion of certain kinds of information when it exists, and for later filling of gaps when the information is not available at the time of file initiation.
   c. Creating a multi-level file of information so that provision may be made for the inclusion of general information, as well as the addition of various levels of specificity as required by the user, either simply because the additional levels of specificity exist and might be useful at a later date or because there is a user requirement for that degree of specificity.
   d. Examining the inter-structuring of files that are part of the larger files but which may be geographically separated.

"2. To provide list-processing capability in the file structure in order to:
   a. Maintain flexibility in the file.
   b. Provide for an efficient means of updating.
   c. Permit additions to files, both in classes existing already in the system and in the entry of new classes of information.
   d. Free the system from the constraints of fixed-length and formatted files.
   e. Permit aggregations of data from files that are geographically separated.

"3. To investigate the techniques of file manipulation in order to provide systems of subfiles, special files, desirable redundancy in exchange for multiple access to information, and the necessary keying or cross-referencing facility required for such a system of multi-level, multi-subject files. This work must take into account also the planning and development of several kinds of computer programs which are required for file maintenance . . .

"4. To determine the kind of organization of information which will most readily permit questioning of the file by different groups of questioners who have varied (and varying) requirements for the kinds of information contained in the file, and who have, furthermore, requirements for different degrees of specificity in the information they are seeking." (Anderson et al., 1966, pp. 2–4).

5.31 "Fossum & Kaskey examine different kinds of file organization and investigate the potential of a 'list ordered file' for economizing on the work-load on a computer when carrying out a search. The data base used is the terms assigned to a number of DDC documents, using the DDC thesaurus. The relevance of this study for this chapter is the analysis of word associations, and the objective of the analysis is, in effect, to permit a certain amount of precoordination of terms, in order to reduce the amount of processing necessary in the retrieval operation. The means to achieving this objective is the determination of the mutual exclusiveness of terms. Unlike the rigorous intellectual marshalling of terms in facet analysis, the procedure here is to determine mutual exclusiveness on the basis of whether or not terms appear together in the indexing of individual documents. The attempt to develop an economic list-organized file, the specific purpose of the work reported here, is abortive, but the technique of handling terms in this way remains an intriguing possibility as a machine aid to the generation of schedules for faceted classification schemes." (Sharp, 1967, p. 102).

5.32 "The fundamental importance of data structures may be illustrated by considering the problem of designing a single language that would be the preferred language either for a purely arithmetic job or for a job in symbol manipulation. Attempts to produce such a language have been disappointing. The difficulty is that the data structures required for efficient implementation in the two cases are entirely different. Perhaps we should recognize this difficulty as a fundamental one, and abandon the quest for an omnibus language which will be all things to all men." (Wilkes, 1968, p. 5).

5.33 "Historically primary preoccupation with three classes of data structures (real-complex scalars and arrays, alphanumeric strings and files, and symbolic lists) have led to three major language developments; exemplified—but not exhaustively defined—by ALGOL, COBOL, and LISP, respectively. A major concern of procedural language designers is the reconcilization of these diverse data types and their transformations with one language." (Perlis, 1965, p. 189).

"Studies in artificial intelligence call for powerful list-processing techniques, and involve such operations as the placing of items on lists, the searching of lists for items according to specified keys, and so on. Languages in which such operations can be easily specified are indicated. The pioneer language in this regard was IPL developed by Newell, Simon and Shaw." (Wilkes, 1964, p. F 1–3).

5.34 "Early list processing languages were invented in order to carry out specific projects of a non-numerical nature. The sequence of languages called IPL . . . Started out in order to provide satisfactory methods of organizing information for work in theorem proving and problem solving, a field in which the amount of storage needed is very variable and unpredictable, and in which the structure of the lists carries important information. LISP . . . was developed partly for the use of a project called the 'Advice Taker' which was intended to operate in a complex way on English statements about situations. A language called FLPL . . . which was embedded in FORTRAN was produced to write programs for proving theorems in geometry. COMIT . . . was devised for language research." (Foster, 1967, p. 3).

5.35 "Furthermore, since a list is itself an ordered set of items which may themselves be lists, there is no limit to the complexity of the structures that can be built up except the total memory space available. Also, there is no restriction to the number of lists on which an item can appear." (Hormann, 1960, p. 14).

"List structures have, as their fundamental property, the substitution rule that allows any symbol in a list to be substituted by a list structure. The natural control procedure for such rules is recu[r]sion: the use of rules whose definition contains calls on itself." (Perlis, 1965, p. 189).

5.36 "List structures allow dynamic storage allocation for units of data larger than can be stored in a single computer word. Normally blocks of consecutive storage cells are allocated for data sets prior to program execution based on estimates of the maximum size of these sets. If the sizes of data sets are variable or unknown, wasteful amounts of storage must be assigned to guard against program failure caused by overflow at some block of assigned storage. Faced with this problem, Newell, Shaw, and Simon organized information in memory into an associative list structure format." (Fuller, 1963, p. 5).

"Since the order relation among items is determined only by links, this relation can be changed simply by changing the links without moving the items physically, thus allowing simple and quick changes of organization of memory content. Processes such as insertion and deletion of items in a list become very simple." (Hormann, 1960, p. 13).

5.37 For example, "list processing is relatively new; none of the forms for the components of list languages has as yet been established as 'standard' even in an informal sense." (Raphael, 1966, p. 67).

"The concept of list processing, or chaining, has been used as a technique for the manipulation of logical data strings for many years and has been formalized as a language for handling data in computer storage. List processing has also been utilized with limited success for the control of data in direct-access storage devices. In general, when list structures are used for external data control, only a subset of the possible data structures is implemented, and the logical and physical relationships are approached as a single entity. Thus, the many ventures into this area are highly individualized, resulting in duplication and incompatibility." (Henry, 1969, p. 2).

5.38 "List processing is a convenient mode of description for many of the more interesting and provocative areas of computer application, but the available languages—such as IPL–V, COMIT, LISP, SIMSCRIPT—require a level of programmer sophistication that makes them almost prohibitive for normal classroom use." (Conway et al., 1965, p. 215).

5.39 "While the list processing languages . . . make it possible to handle reasonably complicated data structures, the programmer is nevertheless faced with a number of difficult problems as soon as he attempts to use such languages in practice . . . it becomes necessary to fit the given data structures into what often turns out to be an unnatural format . . . At the very least, this type of data organization wastes a great deal of storage space . . . Furthermore, the inefficient space allocation also results in extremely slow execution times for the object programs." (Salton, 1966, p. 205).

"The user of list-processing languages is frequently plagued by the lack of memory space. Sophisticated means of 'garbage collection' have become important to circumvent memory space limitations; however, they constitute mostly a palliative that seldom satisfies the user's appetite for extra space." (Cohen, 1967, p. 82).

"In their relation to machines the list processing languages are burdensome, first because the data structures involved may be represented only through explicit links, and second because the free growth and cancellation of structures requires a troublesome administration of the storage." (Naur, 1965, p. 197).

"Powerful software schemes (e.g., the list processing languages) have been developed to deal with the problem of treating scattered data as a contiguous string, but they pay a very heavy price in memory overhead (in some schemes over three-fourths of the available memory is required to handle the addressing mechanisms) and in the processing time required to perform the address arithmetic.

"An alternative solution is proposed here which involves the addition of a small Associative Memory

(AM) to the addressing machinery of the computer (or peripheral direct access storage device). As will be shown, this hardware modification will permit scattered data to appear contiguous, with only a token overhead cost in memory and processing time." (Fischler and Reiter, 1969, p. 381).

5.40 "The process of item deletion involves the elimination of an existing item in the file. This task is complicated by the fact that after deletion, linkage information must be modified if the system is to operate properly. This can be accomplished in two ways. In the first case the item can be physically deleted and each list associated with the item can be searched and the associated link deleted. Alternatively, the specified item can be flagged in the control section. Then during retrieval flagged items are ignored." (Prywes, 1965, p. 20).

"There are several penalties paid for obtaining the flexibility of a memory organized into a list structure. One of these is the requirement for additional memory bits to store appropriate linking addresses. A far more serious penalty is the time required to retrieve symbols from lists and for operations required to add symbols to lists, reorder lists, delete symbols from lists, erase lists, transfer lists to and from bulk storage, and manipulate push-down registers. These tasks are taken out of the hands of the programmer by various list-processing languages, but they still must be performed by the machine." (Fuller, 1963, p. 12).

5.41 "Most list-processing languages have suffered from their inability to deal directly with complex data structure and/or from their inability to perform the complete range of programming language operations upon the data list structures." (Lawson, 1967, p. 358).

5.42 ". . . In many cases, especially among the list-oriented languages, they simply have not geared themselves to the large amounts of data and data processing required in this special field." (Simmons, 1966, p. 214).

"The reason list processing has yet to acquire universal popularity in non-numeric data processing is that, while these mechanics are easy in the list processing language, they can be very time-consuming when performed by a computer, so much so that the economics of use of present-day list processing languages in most information retrieval applications is questionable. Because of the saving in programming time that is possible, however, we may anticipate future hardware and software developments that will enable these methods to be made practical." (Meadow, 1967, pp. 200–201.)

"This suggests that a conventional linked list structure is inadequate for representing map (or picture) structure. Alternative forms might be an associative memory or a more general linked element structure." (Pfaltz et al., 1968, p. 369).

5.43 "It must be said also that numeric information is often awkward to store in terms of list structures, and arithmetic procedures may be correspondingly difficult to perform." (Salton, 1966, p. 208).

"The well-known list structure languages such as LISP were not designed for graphics and are not very efficient or easy to use for such multidimensional problems. They are well suited for processing strings of text but break down when two-way associations between list elements are the rule rather than the exception." (Roberts, 1965, p. 212).

5.44 "The list processing section of the compiler should make it possible to handle variable length data structures, in such a way that each data item may be associated with a variable number of list pointers, as specified by a special parameter." (Salton, 1966, p. 209).

5.45 "It might . . . be useful to think about a general *graph and tree manipulator,* capable of performing most of the common transformations on abstract graphs and trees." (Salton, 1966, p. 209).

"The value of a generalized file processing system is directly related to the variety of *file structures* it can accommodate. With most existing systems, the user is limited to structures having the form of hierarchies or *trees*. For many problems, such structures are either not adequate or not efficient; instead, these problems require structures of the form of *graphs*, of which the tree is a special case. Examples of problems of this type are network and scheduling problems, computer graphic problems, and information retrieval problems." (McGee, 1968, p. F68).

"Most complex data structures can be adequately represented as *directed graphs*. A directed graph is defined informally as a set of labeled points or *nodes*, and a set of directed line segments or *arcs* connecting pairs of nodes. An arc running from node x to node y denotes that the entities represented by x and y are related in some way, e.g., x is superior to y, or x precedes y. If x and y bear multiple relationships to each other, they may be connected by multiple arcs, each arc being labeled with the relation being represented." (McGee, 1968, p. F68).

5.46 "Since Rover has more features that are common to IPLs than any other language, it may be said to be a member of the IPL family. Some additional features are present in Rover which attempt to provide a more powerful tool for synthesizing complex processes. . . .

"The original design of IPL memory structure has only DLs [down links] which, by themselves can form lists and achieve a great flexibility. We are introducing ULs [up links] here in order to give greater flexibility and to overcome some of the difficulties encountered by having only DLs. . . ."

"Since the order relation among items is determined only by links, this relation can be changed simply by changing the links without moving the items physically, thus allowing simple and quick changes of organization of memory content.

Processes such as insertion and deletion of items in a list become very simple. . . .

"Another disadvantage is the loss of ability to compute addresses. Since the order relation is introduced to a set of items only by extending 'adjacency' defined by links, the 'table look-up' feature is lost.

"A part of the seemingly lost feature is regained, and furthermore, an added feature is gained by introducing 'side links' which are extension of ULs and DLs. . . .

"The first item on a list . . . uses its UL to store the name of the list [the location of the cell that contains the name of the first item on the list]. The last item of a list contains the name of the first item as its DL as well as the 'end bit' description.

"This internal convention gives a list the effect of being a ring; having reached to the end item, the processor has an access to the first item as well as the name of the list without backtracking." (Hormann, 1960, pp. 2, 13, 15–16, 21).

5.47 "The Association-Storing Processor (ASP) consists of a language designed to simplify the programming of non-arithmetic problems, together with a number of radically new machine organizations designed to implement this language. These machine organizations are capable of high-speed parallel processing, and take advantage of the low cost of memory and logic offered by large scale integration (LSI).

"The ASP concept has been developed specifically for applications having one or more of the following characteristics:

(1) The data bases are complex in organization and may vary dynamically in both organization and content.
(2) The associated processes involve complex combinations of simple retrieval operations.
(3) The problem definitions themselves may change, often dramatically, during the life of the system." (Savitt et al., 1967, p. 87).

5.48 "Sketchpad's topological file uses a special ring structure that permits storage structure rearrangement with a minimum of searching . . . The use of redundant interconnecting blocks in its list structure gives it the appearance of being ordered more like a tree. This allows fast forward and backward searches for subgroups. The structure used insures that at most two steps must be taken to find either the header block or the previous element." (Coggan, 1967, p. 6).

5.49 "If some connection is deleted, it is not sufficient to just remove the line from the display file. That line represents an association between two elements and may constrain the movement of the elements, the distance between them and their deletion, as well as their external properties (e.g., electrical, program flow, etc.). Thus, each line or other picture element must be attached to an undetermined number of graphical elements and constraints in such a way as to facilitate the processing of these associations." (Roberts, 1965, p. 211).

"A block of elements collects many ties together and thus allows the multi-dimensional associations required for graphical data structures . . . A block is formed from a sequence of registers of any length and contains a blockhead identifier at the top, a group of ring elements and any number of data registers . . . Blocks are used to represent items or entities and the rings form associations between blocks." (Roberts, 1965, pp. 212–213).

"There are two operators for moving around classes, one to go through all members of a class (arrows leaving this item), and one to find all the classes an item belongs to (arrows pointing at this item)." (Roberts, 1965, p. 214).

"Before a new free block is added to the free lists, the block just after it in memory is examined and if it is free also, then the two blocks are merged into one larger free block. This merging technique makes the allocation of variable length blocks almost as efficient as the allocation of fixed length blocks." (Roberts, 1965, p. 213).

5.50 "In the current DEACON work, data is organized into ring structures. These structures are similar in many respects to the plex structures defined by Ross and used by Sutherland in Sketchpad, and are an extension of the notion of list structure." (Thompson, 1966, pp. 354–355).

5.51 "SLIP was the first embedding of a list-processing capability within a higher level language and has a formative ring structure. The idea of rings was crystallized by Sutherland and Roberts and used with data systems designed primarily for graphics and computer-aided design. Roberts has also developed a language to refer to rings (Class Oriented Ring Associative Language: CORAL). In such languages, the associations are built into the structure by allowing blocks of information to be threaded by rings which carry the associations between the blocks of data. This is illustrated . . ., where 'JOHN's' 'parent of' ring goes through 'NUB C' and 'NUB A', which in turn reference 'Edith' and 'Arnold' respectively. Thus John is the parent of both Edith and Arnold. A similar structure has been implemented with PL/1 by Dodd. The duality of certain relationships, such as: 'defined by' and 'defines' or 'to the left of' and 'to the right of', etc., led to the need for a connector block, here illustrated by the three NUBS. In essence, the NUB represents a two-way switch for transferring out of one ring and into another. The subroutines or macros pass along the ring until they arrive at a NUB. They 'switch' it, and pass into the other ring, passing along the second ring (and others as found) picking up information until they return to the original NUB and re-enter the first ring. This allows answers to questions such as 'Who is the mother of Arnold?' as well as 'Who is the son of Mary?' One of the major disadvantages of these structures occurs on adding a new, not previously anticipated, association. The operation either is impossible, requiring a complete re-compilation, or else clumsy, patching on additional blocks . . . and requiring sophisticated garbage collectors. A recent survey by Gray describes these and similar structures." (Ash and Sibley, 1968, p. 145).

5.52 "An interesting variation on the basic list processing technique was described by Cheydleur in 1963. In this technique, a datum is stored just once in memory, but provision is made for many pointers both to and away from a given element. Data redundancy of normal list processing is eliminated at the expense of addressing redundancy. The address bookkeeping becomes quite complex, but it is interesting to note that Cheydleur's concept is applicable to cells of varying sizes. He suggests methods for partitioning strings of symbols so that there is a reasonable distribution of pointers throughout the store. That is, if it can be predicted that the co-occurrence of individual letters or words will be of high frequency, these co-occurrences would be stored in the same cell. Since the storage space taken by pointers competes with data storage requirements, methods for balancing cell size and pointer distribution are quite important." (Climenson, 1966, p. 114).

5.53 "Ring structures are adequate for storing a wide range of richly interrelated data that is pertinent to such functions as intelligence analysis, management planning, and decision making. Typical of these functions are resource allocation problems, in which the pertinent data is an inventory of the resources, their characteristics, and their interrelations. This type of data is specifiable in ring structures." (Craig et al., 1966, p. 366).

5.54 "APL was conceived at the General Motors Research Laboratories to satisfy the need for convenient data association and data handling techniques in a high-level language. Standing for ASSOCIATIVE PROGRAMMING LANGUAGE, it is designed to be embedded in PL/1 as an aid to the user dealing with data structures in which associations are expressed." (Dodd, 1966, p. 677).

5.55 "The principal tool used by this system is the Associative Structure Package (ASP7) implemented by W. A. Newman for the PDP7. It is used to build data structures whose associative properties are expressed using rings, where a ring is a series of addresses in words so that the first points to the next, and so on until the last points back to the first. The first pointer is specially marked and is called a ringstart. The ringstart may point to itself; i.e., the ring may be null." (Pankhurst, 1968, p. 410).

5.56 "On-line interaction introduces into the language picture the possibility of 'conversation'. This possibility, together with the need to bring on-line languages abreast of conventional programming languages, opens an inviting field to research and development." (Licklider, 1965, p. 124).

We note also the following: "*On-line Programming Systems* put the raw power of a computer at the immediate disposal of a human user. Evidence of today's great interest in on-line programming systems is that more and more of them are being used." (Sutherland, 1965, p. 9).

"The on-line nature of time-sharing permits direct man-machine communication in languages that are beginning to approach natural language, at a pace approaching normal human conversation, and in some applications, at graded difficulty levels appropriate to the skill and experience of the user." (Sackman, 1968, p. 1).

"To improve all our on-line systems, we need more and better languages of communication between the man and the machine which are 'natural' in the sense that they are easy to use and fit the task. Why can't I write mathematical equations which look like mathematical equations and have the machine accept, compile and perform them? Why can't I describe network problems to the computer by means of the picture showing the network? Why can't I, in filter design, place poles and zeros on the complex plane? The answer in each case is: I can in principle, but not in practice. As yet, the techniques which let me do these things are not widely used." (Sutherland, 1965, pp. 11–12).

5.57 "Overhead computation can be thought of as degrading the effective operating rate of the processor as seen by the user." (Scherr, 1965, p. 28).

5.58 Examples include, but are not limited to, the following: "With each computation there is associated a set of information to which it requires a high density (in time) of effective reference. The membership of this working set of information varies dynamically during the course of the computation." (Dennis and Van Horn, 1965, p. 11).

"Various problem areas make different demands for data structures and for syntax. The argument is not to restrict specialization to transliteration. It is to avoid unnecessary diversity and to achieve necessary diversity by specializing in the various directions at as high a point on the scale as possible and thus by handling the bulk of the language-implementation process in a uniform way with common facilities." (Licklider, 1965, p. 181).

"Most writers of papers on on-line applications of time-shared systems are universal in their agreement on the importance of interactive languages. They also seem to concur that such languages will differ substantially from the programming languages now in existence, such as FORTRAN, ALGOL, and IPL–V. The difference is primarily due to the new kinds of operations made possible by the remote console through which communication between man and computer takes place." (Davis, 1966, p. 229).

"In programming as well as in hardware design and system organization, time sharing calls for new departures. Perhaps the most significant is the one referred to by the term 're-entrant programs'. When many computer programs are currently active, it is likely that several of them are doing essentially the same thing at the same time. Whenever that is the case, efficiency in use of memory space would be gained if the several programs shared a common subprogram." (Licklider, 1965, p. 26).

5.59 "In artificial intelligence problems, this process [code, run & see, code] must often be prolonged beyond the debugging phase. It is important for the programmer to *experiment* with the working program, making alterations and seeing the effects of the changes. Only in this way can he evaluate it or extend it to cover more general cases." (Teitelman, 1966, p. 2).

"This appears to be the best way to use a truly interactive man-machine facility—i.e., not as a device for rapidly debugging a code representing a fully thought out solution to a problem, but rather as an aid for the exploration of problem solving strategies." (Weizenbaum, 1966, p. 42).

"If computers are to render frequent and intensive service to many people engaged in creative endeavors (i.e., working on new problems, not merely resolving old ones), an effective compromise between programming and *ad hoc* programming is required." (Licklider, 1965, p. 181).

5.60 "Programs very likely to contain errors must be run but must not be permitted to interfere with the execution of other concurrent computations. Moreover, it is an extremely difficult task to determine when a program is completely free of errors. Thus, in a large operational computer system in which evolution of function is required, it is unlikely that the large amount of programming involved is at any time completely free from errors, and the possibility of system collapse through software failure is perpetually present. It is becoming clear that protection mechanisms are essential to any multiprogrammed computer system to reduce the chance of such failure producing catastrophic shutdown of a system." (Dennis, 1965, p. 590).

5.61 "The functional language makes no reference to the specific subject matter of the problem . . . The program must be organized to separate its general problem-solving procedures from the application of these to a specific task." (Newell and Simon, 1959, p. 22).

"There has been a shift away from a concern with difficulty and toward a concern with generality. This means both a concern that the problem solver accept a general language for the problem statement, and that the internal representation be very general." (Newell, 1965, p. 17).

5.62 For example, "Multilang is a problem-oriented language that translates the user's statement of the problem into requests for relevant programs and data in the system's memory. The language was designed specifically to assist in problem-solving and, in so doing, to 'accumulate knowledge'. For example, it may not recognize the term 'eligible voter', but it can be told that an eligible voter is a thing that is 'human', 'age over 21' and either 'born in the U.S.' or 'naturalized'. If these terms have been previously defined, the computer can find an answer to the question; additionally, the next time it is asked about eligible voters, it will know what is meant." (Carr and Prywes, 1965, pp. 88–89).

5.63 "Each user, and each user's program, must be restricted so that he and it can never access (read, write, or execute) unauthorized portions of the high-speed store, or of the auxiliary store. This is necessary (1) for privacy reasons, (2) to prevent a defective program from damaging the supervisor or another user's program, and (3) to make the operation of a defective program independent of the state of the rest in store." (Samuel, 1965, p. 10).

5.64 "The TRAC (Text Reckoning And Compiling) language system is a user language for control of the computer and storage parts of a reactive typewriter system." (Mooers, 1966, p. 215).

"A solution to this problem is to use a machine-independent computer language, designed to operate with a reactive typewriter, to operate the local computer. With this method, the computer acts in place of the human controller to gain access to remote computer systems. This approach is possible only with an extremely versatile language, such as the TRAC language. . . . It is relatively easy to describe in TRAC the set of actions which must be taken in order to make the remote computer perform and bring forth the desired files." (Fox et al., 1966, p. 161).

5.65 "The basic property of symbolic languages is that they can make use in a text of a set of local symbols, whose meaning and form must be declared within the text (as in ALGOL) or is to be deduced by the context (as simple variables in FORTRAN)." (Caracciolo di Forino, 1965, p. 227). However, "it is . . . regrettable from the standpoint of the emerging real-time systems that languages like COBOL are so heavily oriented toward processing of sequential tape file data." (Head, 1963, p. 40).

5.66 Some other recent examples include LECOM, L^6, LISP II, CORAL, and TREET, characterized briefly as follows:

"The compiler language, called LECOM, is a version of COMIT, and is especially designed for small (8K) computers. The microcategorization program was written in LECOM, and assigns an appropriate syntactic category to each word of an input sentence." (Reed and Hillman, 1966, p. 1).

"Bell Telephone Laboratories' Low-Level Linked List Language (L^6, pronounced 'L-six') contains many of the facilities which underlie such list processors as IPL, LISP, COMIT and SNOBOL, but it permits the user to get much closer to machine code in order to write faster-running programs, to use storage more efficiently and to build a wider variety of linked data structures." (Knowlton, 1966, p. 616).

"L^6 . . . is presently being used for a variety of purposes, including information retrieval, simulation of digital circuits, and automatic drawing of flowcharts and other graphical output." (Knowlton, 1966, p. 617).

"The most important features of Lsix which distinguish it from other list processors such as IPL, LISP, COMIT and SNOBOL are the availability of several sizes of storage blocks and a flexible means of specifying within them fields containing data or pointers to other blocks. Data structures are built by appropriating blocks of various sizes, defining fields (simultaneously in all blocks) and filling these fields with data and pointers to other blocks. Available blocks are of lengths 2^n machine words where n is an integer in the range 0–7. The user may define up to 36 fields in blocks, which have as names single letters or digits. Thus the D field may be defined as bits 5 through 17 of the first word of any block. Any field which is long enough to store an address may contain a pointer to another block. The contents of a field are interpreted according to the context in which they are used." (Housden, 1969, p. 15).

"LISP 2 is a new programming language designed for use in problems that require manipulation of highly complex data structures as well as lengthy arithmetic operations. Presently implemented on the AN/FSQ-32V computer at the System Development Corporation . . . A particularly important part of the program library is a group of programs for bootstrapping LISP 2 onto a new machine. (Bootstrapping is the standard method for creating a LISP 2 system on a new machine). The bootstrapping capability is sufficiently powerful so that the new machine requires no resident programs other than the standard monitor system and a binary loader." (Abrahams et al., 1966, pp. 661–662).

"This list structure processing system and language being developed at Lincoln is called CORAL (Class Oriented Ring Association Language). The language consists of a set of operators for building, modifying, and manipulating a list structure as well as a set of algebraic and conditional forms." (Roberts, 1965, p. 212).

"TREET is a general-purpose list processing system written for the IBM 7030 computer at the MITRE Corporation. All programs in TREET are coded as functions. A function normally has a unique value (which may be an arbitrarliy complex list structure), a unique name, and operates with zero or more arguments." (Bennett et al., 1965, pp. 452–453).

5.67 "The growing importance of the family concept accentuates the need for levels of software. These levels of software will be geared to configuration size instead of family member. In other words, the determining factor will be the amount of memory and the number of peripheral units associated . . ." (Clippinger, 1965, p. 210).

"The advantages of high-level programming languages . . . [include] higher machine independence for transition to other computers, and otherwise for compatibility with hardware . . . [and] better documentation (compatibility among programs and different programmers)." (Burkhardt, 1965, p. 4).

"The user needs to employ data structures and processes that he defined in the past, or that were defined by colleagues, and he needs to refresh his understanding of those objects. The language must therefore have associated with it a metalanguage and a retrieval system. If there is more than one working language, the metalanguage should be common to all the languages of the system." (Licklider, 1965, p. 185).

"The over-all language will be a system because all the sublanguages will fall within the scope of one metalanguage. Knowing one sublanguage will make it easier to learn another. Some sublanguages will be subsets of others." (Licklider, 1965, p. 126).

5.68 "The most immediate need is for a general *compiling system* capable of implementing a variety of higher-level languages, including in particular, string manipulations, list processing facilities, and complete arithmetic capabilities." (Salton, 1966, p. 208).

5.69 Licklider, 1965, p. 119.

"It will be absolutely necessary, if an effective procognitive system is ever to be achieved, to have excellent languages with which to control processing and application of the body of knowledge. There must be at least one (and preferably there should be only one) general, procedure-oriented language for use by specialists. There must be a large number of convenient, compatible field-oriented languages for the substantive users." (Licklider, 1965, p. 67).

5.70 "There is, in fact, an applied scientific *lag* in the study of computer programmers and computer programming—a widening and critical lag that threatens the industry and the profession with the great waste that inevitably accompanies the absence of systematic and established methods and findings and their substitution by anecdotal opinion, vested interests, and provincialism." (Sackman et al., 1968, p. 3).

"Work on programming languages will continue to provide a basis for studies on languages in general, on the concept of grammar, on the relation between actions, objects and words, on the essence of imperative and declarative sentences, etc. Unfortunately we do not know yet how to achieve a definition of programming languages that covers both their syntactic and pragmatic aspects. To this goal a first step may be the thorough study of special languages, such as programming languages for machine tools, and simulation languages." (Caracciolo di Forino, 1965, p. 6).

5.71 "As Levien & Maron point out, and Bobrow analyzes in detail, natural language is much too syntactically complex and semantically ambiguous to be efficient for man-machine communication. An alternative is to develop formalized languages with a simplified syntax and vocabulary. Examination of several query languages, for example, COLINGO and GIS, reveals a general (and natural) dependence on, and adaptation of, the rules of formal logic. However, even with English words for logical operations, relations, and object names, formal query languages have been a less-than-ideal solution to the man-machine communication problem. Except for the simplest queries, punctuating a nested Boolean logical statement can be tricky and can lead to errors. Furthermore, syntactic problems aside, a common difficulty arises when the user does not know the legal names of the data for which he is searching or the structural relationships among the data items in the data base, which may make one formulation of his query very difficult and expensive to answer whereas a slightly altered one may be simple to answer." (Minker and Sable, 1967, p. 136).

"The possibility of user-guided natural-language programming offers a promise of bridging the man-machine communication gap that is today's greatest obstacle to wider enjoyment of the services of the computer." (Halpern, 1966, p. 649).

"Such a language would be largely built by the users themselves, the processor being designed to facilitate the admission of new functions and notation of any time. The user of such a system would begin by studying not a manual of a programming language, but a comparatively few pages outlining what the computer must be told about the location and format of data, the options it offers in output media and format, the functions already available in the system, and the way in which further functions and notation may be introduced. He would then describe the procedure he desired in terms natural to himself." (Halpern, 1967, p. 143).

5.72 "Further investigation is required in searching and maintaining relationships represented by graph structures, as in 'fact retrieval' systems. Problems in which parts of the graph exist in one store while other parts are in another store must be investigated, particularly when one breaks a link in the graphs. The coding of data and of relations also needs much work." (Minker and Sable, 1967, p. 151).

5.73 "This program package has been used in the analysis of several multivariate data bases, including sociological questionnaires, projective test responses, and a sociopolitical study of Colombia. It is anticipated that the program will also prove useful in pattern recognition, concept learning, medical diagnosis, and so on." (Press and Rogers, 1967, p. 39).

5.74 "The execution of programs at different installations whose total auxiliary storage capacities are made up of different amounts of random access storage media with different access characteristics can be facilitated by the organization of the auxiliary storage devices into a multilevel storage hierarchy and the application of level changing." (Morenoff and McLean, 1967, p. 1).

5.75 "A systems problem that has received considerable attention is how to determine which data should be in computer memory and which should be in the various members of the mass storage hierarchy." (Bonn, 1966, p. 1865).

"The key requirement in multiprogramming systems is that information structures be represented in a hardware-independent form until the moment of execution, rather than being converted to a hardware-dependent form at load time. This requirement leads directly to the concept of hardware-independent virtual address spaces, and to the concept of virtual processors which are linked to physical computer resources through address mapping tables." (Wegner, 1967, p. 135).

5.76 "With respect to the central processing unit, the major compromise of future needs with present economy is the limitation on addressing capacity." (Brooks, 1965, p. 90).

"Other major problems of large capacity memories are related to the tremendous amount of electronic circuitry required for addressing and sensing." (Kohn, 1965, p. 132).

5.77 For example, "the problem of assigning locations in name space for procedures that may be referenced by several system functions and may perhaps share references to other procedures, is not widely recognized and leads to severe complications when implementation is attempted in the context of conventional memory addressing." (Dennis and Glaser, 1965, p. 6).

5.78 "A particularly troublesome phenomenon, thrashing, may seriously interfere with the performance of paged memory systems, reducing computing giants (Multics, IBM System 360, and others not necessarily excepted) to computing dwarfs. The term thrashing denotes excessive overhead and severe performance degradation or collapse caused by too much paging. Thrashing inevitably turns a shortage of memory space into a surplus of processor time." (Denning, 1968, p. 915).

5.79 ". . . Global weather prediction. Here a three-dimensional grid covering the entire world must be stepped along through relatively short periods of simulated time to produce a forecast in a reasonable amount of time. This type of problem with its demand for increased speed in processing large arrays of data illustrates the applicability of a computer designed specifically for array processing." (Senzig and Smith, 1965, p. 117).

"Most engineering data is best represented in the computer in array form. To achieve optimum capability and remove the restrictions presently associated with normal FORTRAN DIMENSIONed array storage, arrays should be dynamically allocated. Dynamic allocation of data achieves the following:

"1. Arrays are allocated space at *execution* time rather than at *compilation* time. They are only allocated the amount of space needed for the problem being solved. The size of the array (i.e., the amount of space used) may be changed at any time during program execution. If an array is not used during the execution of a particular problem, then no space will be allocated.

“2. Arrays are *automatically* shifted between primary and secondary storage to optimize the use of primary memory.

“Dynamic memory allocation is a necessary requirement for an engineering computer system capable of solving different problems with different data size requirements. *A dynamic command structured language requires a dynamic internal data structure.* The result of dynamic memory allocation is that the size of a problem that can be solved is virtually unlimited since secondary storage becomes a logical extension of primary storage.” (Roos, 1965, p. 426).

5.80 “Any language which lacks provision for performing necessary operations, such as bit editing for telemetered data, forces the user to write segments in assembly language. This destroys the machine independence of the program and complicates the checkout.” (Clippinger, 1965, p. 207).

5.81 “Thus one must consider not only whether the logical possibilities of a new device are ignored when one is restricted to a binary logic, but also whether one is sufficiently using the signals when only one of the parameters characterizing that signal is used.” (Ring et al., 1965, p. 33).

5.82 “For a variety of reasons, not the least of which is maturing of integrated circuits with their low cost and high density, central processors are becoming more complex in their organization.” (Clippinger, 1965, p. 209).

5.83 “No large system is a static entity—it must be capable of expansion of capacity and alteration of function to meet new and unforeseen requirements.” (Dennis and Glaser, 1965, p. 5).

“Changing objectives, increased demands for use, added functions, improved algorithms and new technologies all call for flexible evolution of the system, both as a configuration of equipment and as a collection of programs.” (Dennis and Van Horn, 1965, p. 4).

“By pooling, the number of components provided need not be large enough to accommodate peak requirements occurring concurrently in each computer, but may instead accommodate a peak in one occurring at the same time as an average requirement in the other.” (Amdahl, 1965, pp. 38–39).

5.84 “The use of modular configurations of components and the distributed executive principle . . . insures there are multiple components of each system resource.” (Dennis and Glaser, 1965, p. 14).

“Computers must be designed which allow the incremental addition of modular components, the use by many processors of high speed random access memory, and the use by many processors of peripheral and input/output equipment. This implies that high speed switching devices not now incorporated in conventional computers be developed and integrated with systems.” (Bauer, 1965, p. 23). See also note 2.52.

5.85 “The actual execution of data movement commands should be asychronous with the main processing operation. It should be an excellent use of parallel processing capability.” (Opler, 1965, p. 276).

5.86 “Work currently in progress [at Western Data Processing Center, UCLA] includes: investigations of intra-job parallel processing which will attempt to produce quantitative evaluations of component utilization; the increase in complexity of the task of programming; and the feasibility of compilers which perform the analysis necessary to convert sequential programs into parallel path programs.” (Digital Computer Newsletter **16,** No. 4, 21 (1964)).

5.87 “The motivation for encouraging the use of parallelism in a computation is not so much to make a particular computation run more efficiently as it is to relax constraints on the order in which parts of a computation are carried out. A multiprogram scheduling algorithm should then be able to take advantage of this extra freedom to allocate system resources with greater efficiency.” (Dennis and Van Horn, 1965, pp. 19–20).

5.88 “The parallel processing capability of an associative processor is well suited to the tasks of abstracting pattern properties and of pattern classification by linear threshold techniques.” (Fuller and Bird, 1965, p. 112).

5.89 “The idea of DO TOGETHER was first mentioned (1959) by Mme. Jeanne Poyen in discussing the AP 3 compiler for the BULL Gamma 60 computer.” (Opler, 1965, p. 307).

5.90 “To date, there have been relatively few attempts made to program problems for parallel processing. It is not known how efficient, for example, one can make a compiler to handle the parallel processing of mathematical problems. Furthermore, it is not known how one breaks down problems, such as mathematical differential equations, such that parts can be processed independently and then recombined. These tasks are quite formidable, but they must be undertaken to establish whether the future development lies in the area of parallel processing or not.” (Fernbach, 1965, p. 82).

5.91 For example, in machine-aided simulations of nonsense syllable learning processes, Daly et al. comment: “Presuming that, for the parallel logic machine, the nonsense syllables were presented on an optical retina in a fixed point fixed position set-up, there would be a requirement for recognizing $(26)^3$ or about 10^4 different patterns. If three sequential classification decisions were performed on the three letters of the nonsense word only 3(26) or 78 different patterns would be involved.

"In the above simple example converting from purely parallel logic to partially sequential processing reduced the machine complexity by two order(s) of magnitude. The trend is typical and may involve much larger numbers in a more complicated problem. Using both parallel and sequential logic as design tools the designer is able to trade-off time versus size and so has an extra degree of freedom in developing his system." (Daly et al., 1962, pp. 23–24).

5.92 ". . . The SOLOMON concept proposed by Slotnick at Westinghouse. Here it is planned that as many as a thousand independent simple processors be made to operate in parallel under an instruction from a network sequencer." (Fernbach, 1965, p. 82).

"Both the Solomon and Holland machines belong to a growing class of so-called 'iterative machines'. These machines are structured with many identical, and often interacting, elements.

"The Solomon machine resulted from the study of a number of problems whose solution procedures call for similar operations over many pieces of data. The Solomon system contains, essentially, a memory unit, an instruction unit, and an array of execution units. Each individual execution unit works on a small part of a large problem. All of the execution units are identical, so that all can operate simultaneously under control of the single instruction unit.

"Holland, on the other hand, has proposed a fully distributed network of processors. Each processor has its own local control, local storage, local processing ability, and local ability to control pathfinding to other processors in the network. Since all processors are capable of independent operation, the topology leads to the concept of 'programs floating in a sea of hardware'." (Hudson, 1968, p. 42).

"The SOLOMON (Simultaneous Operation Linked Ordinal MOdulator Network), a parallel network computer, is a new system involving the interconnections and programming, under the supervision of a central control unit, of many identical processing elements (as few or as many as a given problem requires), in an arrangement that can simulate directly the problem being solved." (Slotnick et al., 1962, p. 97).

"Three features of the computer are:

(1) The structure of the computer is a 2-dimensional modular (or iterative) network so that, if it were constructed, efficient use could be made of the high element density and 'template' techniques now being considered in research on microminiature elements.

(2) Sub-programs can be spatially organized and can act simultaneously, thus facilitating the simulation or direct control of 'highly-parallel' systems with many points or parts interacting simultaneously (e.g., magneto-hydrodynamic problems or pattern recognition).

(3) The computer's structure and behavior can, with simple generalizations, be formulated in a way that provides a formal basis for theoretical study of automata with changing structure (cf. the relation between Turing machines and computable numbers)." (Holland, 1959, p. 108).

5.93 ". . . The development of the Illiac III computer, which incorporates a 'pattern articulation unit' (PAU) specifically designed for performing local operations in parallel, on pictures or similar arrays." (Pfaltz et al., 1968, p. 354).

"One of the modules of the proposed ILLIAC III will be designed as a list processor for interpreting the list structure representation of bubble chamber photographs." (Wigington, 1963, p. 707).

5.94 "I use this term ['firmware'] to designate microprograms resident in the computer's control memory, which specializes the logical design for a special purpose, e.g., the emulation of another computer. I project a tremendous expansion of firmware—obviously at the expense of hardware but also at the expense of software. . . .

"Once the production of microprogrammed computers was commenced, a further area of hardware-software interaction was opened via microprogramming. For example, more than one set of microprograms can be supplied with one computer. A second set might provide for execution of the order set of a different computer—perhaps one of the second generation. Additional microprogram sets might take over certain functions of software systems as simulators, compilers and control programs. Provided that the microsteps remain a small fraction of a main memory access cycle, microprogramming is certain to influence future software design." (Opler, 1966, p. 1759).

"Incompatibility between logic and memory speeds . . . has also led to the introduction of microprogramming, in which instruction execution is controlled by a read-only memory. The fast access time of this memory allows full use of the speed capabilities offered by the fast logic." (Pyke, 1967, p.161).

"A microprogrammed control section utilizes a macroinstruction to address the first word of a series of microinstructions contained in an internal, comparatively fast, control memory. These microinstructions are then decoded much as normal instructions are in wired-in control machines . . ." (Briley, 1965, p. 93).

"The microprogrammed controller concept has been used to implement the IBM 2841 Storage Control Unit, by means of which random access storage devices may be connected to a System/360 central processor. Because of its microprogram implementation, the 2841 can accommodate an unusually wide variety of devices, including two kinds of disk storage drive, a data cell drive, and a drum." (McGee and Petersen, 1965, p. 78).

"In microprogram control, the functions of the controller [for source experimental data automation] are vested in a microprogram which is stored in a control memory. The microprogram is made up of microinstructions which are fetched in sequence from memory and executed. The microinstructions control a very general type of hardware configuration, so that merely by changing the microprogram, the functions available in the controller can be made to range between wide limits." (McGee and Petersen, 1965, p. 78).

5.95 "The computer science community has not recognized (let alone faced up to) the problem of anticipating and dealing with very large individual differences in performing tasks involving man-computer communications for the general public." (Sackman, et al., 1968, pp. 9–10).

5.96 "The dynamic nature of multiprogram on-line computation should have a strong influence on memory organization." (Lock, 1965, p. 471).

"The tradeoffs in speed, cost, logic complexity, and technology are inherent to the design of *systems* and are not separable in spite of the good intentions of the semiconductor manufacturers or the abstract logicians." (Howe, 1965, p. 506).

5.97 "I cannot emphasize too strongly the interdependence of hardware and software (the statements of procedures, implementation of which in a given equipment configuration constitutes the processing capability)." (Schultz, 1967, p. 20).

6. Advanced Hardware Developments

6.1 "It will be necessary to scan the photochromic plane very quickly and accurately, with an extremely fine pinpoint of light. Lockheed Electronics has been exploring a method of rapidly deflecting a laser beam, nonmechanically, in two dimensions. The technique is based on refraction of the beam by acoustic energy." (Reich and Dorion, 1965, p. 573).

6.2 "Laser holography is finding some practical applications. Technical Operations, Inc., of Burlington, Mass., says it has delivered what is believed to be the first operational holography equipment to Otis Air Force Base in Massachusetts, where it will be used to photograph fog in three dimensions." (Electronics **38,** No. 20, 25 (1965).)

6.3 "A work horse of unsuspected power was harnessed in 1960 when the first operating laser was demonstrated at Hughes Research Laboratories." ("The Lavish Laser", 1966, p. 15).

"The first device to be successfully operated was a pulsed ruby laser." (Baker and Rugari, 1966, p. 37). Further reference is to Maiman, 1960.

6.4 "Gas lasers are the most monochromatic, fluorescent crystal lasers are the most powerful, while semiconductor lasers are the smallest, the most efficient and can be directly modulated." (Gordon, 1965, p. 61).

6.5 This area of technological development has already received such a responsive interest, in general, that Lowry-Cocroft Abstracts, Evanston, Illinois, provides a punched card abstracts service in the field of laser developments.

6.6 "The development of the laser as a practical, continuous, coherent light source has created a new display technology, that of the laser-beam display. This type display can be considered to be analogous to well-known electron-beam type displays, e.g., the cathode ray tube and the liquid-light valve. The primary difference is that the electron beam is constrained to a vacuum environment and requires a special screen for the emission or control of light while a laser beam can operate in air and be the source of light directly. . . .

"The major significance of the laser in a display system is that all of the energy is usable since the apparent source of this light is a diffraction-limited point-dipole radiator. Conventional light sources such as tungsten filament or a mercury arc are quite wasteful since light is emitted into a 360-degree solid angle from a relatively large area. When these light sources are used to illuminate the limited aperture of a practical optical system, only a small fraction of the emitted light is used." (Baker and Rugari, 1966, p. 37).

6.7 "Since the polarization of the light can be electro-optically switched in nanoseconds, the inherent speed of the electro-optic effect does not limit the rate of data projection. However, in practice the rate is limited by dissipation in the deflection elements and by the stored-energy requirements of the associated circuitry. Therefore the voltage across the half-wave plate and the loss tangent of the dielectric are important parameters." (Soref and McMahon, 1965, p. 59).

6.8 "Coherent light from lasers will provide a revolutionary increase in the volume of communication that can be sent over a single pathway." (McMains, 1966, p. 28).

"In communications the laser can far surpass conventional facilities. Operating on frequencies many times higher than radio, it can carry many times as much information. In fact, one laser beam could carry thousands of TV signals at once. Experiments now under way with lasers enclosed in large pipes indicate their wide employment for mass communications for the future." ("The Lavish Laser", 1966, p. 16).

"As man goes farther away from the earth in space exploration, laser communication will become more important, because the problems of power supply and background noise besetting conventional microwaves at distances beyond the moon will be minimized. In an example of speed comparison, eight hours were required to transmit the pictures from Mars, but a laser beam could carry even television images across the same distance in a few minutes." ("The Lavish Laser", 1966, p. 16).

"The laser—with its extremely narrow beam due to its short wavelength, notwithstanding its high quantum and background noise—offers the possibility of surpassing RF techniques in its ability to satisfy deep-space requirements." (Brookner et al., 1967, p. 75).

In terms of immediate practicality, however, experiments in the use of laser techniques for data transmission have been limited to very short distances. For example, "television signals have been transmitted on laser beams for distances of the order of a mile in clear weather . . ." (Gordon, 1965, p. 60), and "the Lincoln Laboratory developed an optical communications system based on an array of multiple semiconductor lasers that propagates pulses through a 1.8-mile path in most weather conditions." (Swanson, 1967, p. 38).

Goettel therefore concludes that "years of continued research remain before an economical laser-transmission system becomes a reality." (Goettel, 1966, p. 193).

6.9 "Scientists from the Honeywell Research Center in Minneapolis say that optical techniques provide a means for increasing information storage density above the levels obtainable with current technology. A memory element under development will permit over two million bits of information to be stored on a surface the size of a dime. The information can be read at the rate of 100 million bits per second using a low power—1 milliwatt—laser." (Bus. Automation **13**, No. 12, 69 (Dec. 1967).)

6.10 "The laser will transform Raman spectroscopy from a time-consuming tool of limited usefulness to an important analytical technique; for example, the hour-long exposures of Raman spectra on photographic plates are eliminated. Raman spectroscopy with gas-laser beams should have widespread application in analytical chemistry and solid-state physics." (Bloembergen, 1967, p. 85).

"The microscopic electrified fluid streams studied occur at high speed, and are virtually impossible to record with a conventional optical microscope or imaging system. In order to overcome the working-distance and depth-of-field limitations of the classical microscope, a two-step imaging process (holographic photomicroscopy) of high resolution was developed and applied to the study of the electrostatic charging process. In this technique, one first records the optical interference pattern of the 'scene', and then uses this record to reconstruct the original scene. The reconstructed scene can be leisurely examined with conventional optical systems of limited object volume . . .

"The practical consequences of pulsed laser holographic photomicroscopy go beyond the requirements of the present application. Reasonable projection would indicate application to scientific studies that involve moving unpredictable phenomena of either uncertain or changing location. Physical applications include terminal and in-flight ballistics, aerosol-size distributions, cloud physics, studies of sprays, and combustion and rocket-exhaust studies, among others." (Stephens, 1967, p. 26).

"Recently at Boulder, Colo., Michael McClintock of the NBS Institute for Basic Standards used an argon laser as a source to obtain and analyze the Raman and Rayleigh spectra in several transparent liquids . . . His mathematical evaluation of the experimental data related scattered light spectra to viscosity, to molecular rotation and vibration, and to certain molecular concentrations in mixtures of two unassociated liquids. Analysis of the Raman spectrum also provided new data on molecular coupling . . .

"In general, the beam from an argon ion laser was first passed through a dispersing prism to eliminate all but the 4880-angstrom radiation. The light was then examined from various angles by a spectrometer. Photomultiplier tubes served to increase the intensity of the spectral lines so that they could be recorded." ("Laser Applied to Molecular Kinetics Studies", 1968, p. 242).

6.11 "A very special hologram, called a spatial filter, has the capability of comparing two patterns and producing a signal which is a function of the correlation or similarity of the patterns. Experimentally, it has been found that complicated, natural objects with irregular patterns can be recognized with greater confidence than can man-made objects which tend to be geometrically symmetrical. Fingerprints, because of their randomness, appear to be ideal objects for the spatial filtering method of recognition . . .

"The spatial filtering method of fingerprint recognition has several advantages over other methods of recognition.

"Recognition is instantaneous, limited only by the mechanical pattern input mechanism.

"Partial prints can be recognized. As long as the information which is available does correlate, recognition will take place even though one of the two patterns being compared is incomplete. This property is especially advantageous when you are attempting to correlate partial latent prints with complete recorded prints." (Horvath et al., 1967, pp. 485, 488).

6.12 "A laser image processing scanner (LIPS), able for the first time to quantize high resolution photographs for computer manipulation, has been developed by CBS Laboratories . . . and accepted by the Air Force . . . LIPS can simultaneously digitize a developed high-resolution photograph from a negative and produce a much more detailed negative from the computer image adjacent to the original on the same drum. This makes it much easier for a photo interpreter to recognize important details . . .

"The Air Force system uses a commercial helium-neon gas laser to produce black and white images . . . However, color photos could be produced by substituting an argon ion laser system . . .

"Elements of LIPS include a laser light source focused on a five microns spot size on the negative being digitized in turn feeding into a linearly scanning microdensitometer and a computer buffer storage.

"On reconstruction of the higher quality negative on the same drum, the same laser is employed in combination with an optical modulator in duplicate scanning . . ." (Electronic News **14,** No. 714, 38 (June 23, 1969).)

"When the Air Force permitted CBS Labs to talk about its high-resolution laser-scanning system (part of Compass Link) used to transmit reconnaissance photos from Vietnam to the Pentagon in minutes [Electronics, April 14, p. 56], CBS officials were optimistic about the possibility of broader applications. A step in that direction has been taken with the modification of the laser scanner so that it can convert high-resolution photos for handling by a computer.

"Called LIPS-laser image processing scanner—the system digitizes the image, then feeds the signal through a buffer to an IBM 360/40 computer. The computer processes the picture to emphasize fine details or improve the contrast. The reconstructed image is then read out of the computer onto photographic film. Thus, LIPS enables the photo interpreter to manipulate his picture to bring out any desired detail with a high degree of resolution.

"Routine work. In operation, the interpreter tells the computer what areas he wants emphasized. For example, he could call for a routine that would bring out high-frequency detail. If the finished picture were unsatisfactory he could go to a routine that not only would emphasize high-frequency detail, but also would suppress or clean up large areas of black.

"LIPS uses a sequential scan to attain a resolution of 100 lines per millimeter. It can digitize, or record from digital data, a 1.8-centimeter-square area in 15 minutes; that's at least twice as fast as conventional scanners such as those used on the Ranger moon probes.

"CBS says the advantages of LIPS—high resolution and geometric fidelity, high-speed read-write rates, and operation in standard room lighting—can be used by map makers, meteorologists, or news organizations." (Electronics **42,** No. 13, 46 (June 23, 1969)).

6.13 "Laser photographs, called holograms, are true three-dimensional representations, and the process of holography not only provides a means for lensless microscopy but may make possible microscopic systems at wavelengths where lenses are not now available." ("The Lavish Laser", 1966, p. 15).

"The original idea of holography and specifically, spatial filtering dates back to 1886 when Ernst Abbe suggested their existence. However, it remained for Dennis Gabor to show in 1951 that a hologram, which has little recognizable information could be 'reconstructed' to a normal recognizable image. Various other workers showed his analysis to be correct. Spatial filtering was investigated at about the same time by Marechal and others primarily as a means of improving photographic images. These pioneers demonstrated that the concepts of holography and spatial filtering would work, but they were handicapped by the lack of a strong source of coherent light. The advent of the laser in 1960 as a source of essentially a single wavelength of light excited new interest in the field of holography. Scientists at General Electric demonstrated the feasibility of using a two-beam holographic spatial filter as a means for recognizing patterns. A. Vander Lugt, at the University of Michigan, also investigated methods by which two-beam spatial filters could be produced." (Horvath et al., 1967, p. 485).

"Laser beams will be used to print the catalogs and newspapers of the future using a new technique developed by Radio Corporation of America. Announcement of the development of the technique that can eliminate the need to print in signatures was made last month by the company. The method uses the intense light produced by the laser to fuse powdered ink spread over the paper to reproduce the original. Excess ink is removed by vacuum.

"The image comes from a photograph of the material to be printed—half-tones, line drawing or newspaper page—on a transparency. The image is transferred with the aid of a laser beam to a hologram or lensless photograph which serves as a permanent plate. A separate hologram is used for each page.

"Dr. Kenneth H. Fishbeck, a technical advisor at the David Sarnoff Research Center, Princeton, N.J., and holder of the patent, said publishers will be able to eliminate signatures since the new process reproduces pages in sequence, from title to index. He claims publishers could almost print on demand." (SPIE Glass **5,** No. 1, 12 (June 1969)).

6.14 "Dillon et al. have proposed and operated a limited-population memory using a ferramagnetic garnet and driven by a laser beam." (Kump and Chang, 1966, p. 255; see also Dillon et al., 1964).

6.15 Reimann reports that: "The neuristor laser computer, conceived at RCA, is an 'all-optical' computer in which all information and control signals are in the form of optical energy . . .

"A theoretical study of the neuristor concept in form of Fiberglas lasers concluded that the fundamental requirements of a neuristor line could, at least in principle, be met with lasers . . .

"The main result of the laser neuristor feasibility study was the conclusion that lasers are capable of satisfying all the requirements for digital devices. It was shown that, in addition to the neuristor-type logic, lasers in form of resonators and amplifiers can have input-output characteristics that resemble those of conventional logic circuits such as gates or flipflops." (Reimann, 1965, pp. 250–251).

"Fiber-optic elements, with appropriate concentrations of active emissive ions and passive absorptive ions, are the basic components of this system. The computer is powered by being in a continuous light environment that provides a constant pump power for maintaining an inverted population of the emissive ions. Among the potentially attractive features of such a system are the freedom from power-supply connections for individual circuits, the possibility of transmission of signals without actual connections between certain locations, and a promise of high-speed operation." (Reimann and Kosonocky, 1965, p. 182).

6.16 "The feasibility of machining resistive and capacitive components directly on thin film metallized substrates with a laser has been demonstrated. Tantalum films can be shaped into resistor geometries and trimmed to tolerance by removing metal. These films also can be oxidized to value using the laser beam as the heat source. Resistors can be made with tolerances in value of less than ±0.1 per cent. . . .

"Pattern generation by laser machining has been demonstrated on various thin films as well as on electroplated films. Vaporized lines as fine as 0.25 mil are readily attainable in thin films, as are 0.4 mil lines in plated films. Much narrower lines may be obtained under particularly well-controlled conditions. Uniform lines as fine as 1 micron have been scribed in thin films on sufficiently flat substrates. These films have been removed with minimum effect to the substrate surface." (Cohen et al., 1968, p. 403).

"Semiconductor laser digital devices offer an improvement in information processing rates of one to two orders of magnitude over that expected from high-speed integrated transistor circuits. Data processing rates of 10 to 100 gigabits per second may be possible using semiconductor lasers. However, the technology for fabricating low-power laser circuits is still undeveloped and low-temperature operation may be required." (Kosonocky and Cornely, 1968, p. 1).

"Laser digital devices may be used for general-purpose logic circuits in very much the same way that transistors are now used, except that all of the processing is done with optical rather than electric signals." (Reimann and Kosonocky, 1965, p. 183).

"Semiconductor current-injection lasers are most attractive for digital devices because of their small size, high pumping efficiency, and high speed of operation." (Reimann and Kosonocky, 1965, p. 194).

"The utility of a laser as a tool for fabricating thin film circuits results primarily from the spectral purity and degree of collimation of the laser light. These characteristics allow the beam to be focused to a very fine and intense spot. The high heat flux which occurs when the light is absorbed by the target material, and the sharp definition and localized nature of the working region allow heating, melting, or vaporizing minute amounts of material, with minimum effect to adjacent material or components." (Cohen et al., 1968, p. 386).

6.17 See Hobbs, 1966, p. 42.

6.18 "A new laser data storage/retrieval system that provides a 1000-time increase in packing density over conventional mag tape, an error rate of 1×10^8 or better, permanent (nonerasable) storage, a transfer rate of 4 megabits/sec., and instantaneous read-while-write verification has been developed by Precision Instrument Co., Palo Alto, Calif.

"A working demonstrator of the 'Unicon' system uses a 1-watt argon gas laser, which makes a hole in the metallic coating of a mylar-base tape wrapped around a drum. The current system, using 5-micron holes, offers a packing density of 13 million bits/sq. in.

"Readout is accomplished by reducing the laser power; beam reflection or non-reflection indicates nonholes or holes. The tape being used on the current system offers storage equivalent to 10 2400-ft. reels of 800 bpi tape. The system can serve on- and off-line, and is capable of recording analog, FM or video data, all of which require high speed." (Datamation **14,** No. 4, 17 (Apr. 1968)).

6.19 "By early 1968, Precision Instrument Co. had developed a massive-scale laser recorder/reader storage system, but the first order for the device was not received until this year. Ed Gray, the chief engineer on the UNICON (Unidensity Coherent Light Recorder/Reproducer) Laser Mass Memory System, said that convincing the first potential customers that they should acquire a $500K to $1 million memory system was not easy, especially when you had to 'tell someone that you were not going to store data with magnetics like God intended.' Now that the first order has been placed, by Pan American Petroleum Corp. of Tulsa, Oklahoma, Mr. Gray feels that the systems will move a little faster in the marketplace.

"The $740K system placed with Pan American is to be installed with all requisite software about March of 1970. Four other potential customers, including some government agencies and a private credit-reporting firm, are also expected to place orders." (Datamation **15,** No. 3, 116 (Mar. 1969).)

6.20 "The National Archives and Records Service has begun a cost-effectiveness study of archival storage systems in an effort to shrink its mag tape library, which contains one million plus reels. The study, due for completion next month, is using the capabilities of Precision Instruments' Unicon device as a model. The Unicon employs a laser-etched aluminum strip with a 30-year shelf life." (Datamation **14,** No. 10, 171 (Oct. 1968)).

6.21 "Honeywell scientists are investigating a method that uses a laser for mass storage and retrieval of information in computer memory. Although emphasizing that development is still in the research stage and may be several years away from practical application, the researchers believe the discovery is a possible key to inexpensive mass storage of data for the enormous computer networks envisioned for the 1970's." (Commun. ACM **11,** 66 (Jan. 1968)).

6.22 "The system . . . uses a modulated laser beam to inscribe data onto photosensitive discs . . . Each disc contains 3, 100 tracks with a capacity of 67,207 bits per track, including error corrections bits. The storage unit holds 2, 600 discs, stored on edge, in four [or eight] trays . . . two auxiliary disc banks can be added to achieve the maximum memory capacity . . . of 150 billion characters. The reader reaches any piece of information on the 3, 100 tracks (per disc) within 15 milliseconds . . ." (Business Automation **12,** No. 6, 84 (1965)).

A CW helium-neon laser is used to "achieve real-time writing of information on the system's photosensitive memory discs." (Connolly, 1965, p. 4).

6.23 "A method for producing erasable holograms may enable an optical memory to store 100 million bits in a film one inch square.

"The memory could be read out, erased and reused repeatedly, according to Dr. William Webster, vice president in charge of RCA Laboratories.

"Information can be written into the magnetic film in 10 billionths of a second, and erased in 20 millionths of a second. Laser light split into two beams, one going directly to the film and the other going to the information bit pattern, interferes constructively to produce heat and consequently a realignment of atoms.

"Where the two beams interfere destructively, nothing happens." (Data Proc. Mag. p. 21 (Sept. 1969)).

6.24 In the IBM-laser system developed for Army Electronics Command and installed at Fort Monmouth, it is noted that: "Through employment of a deflection technique, the shaft of light can be focused on 131,072 distinct points within a space smaller than a match head. . . . To provide a readout in printed form, the laser beam can scan through a mask inscribed with the alphabet and other symbols and—through the action of light-bending (deflection) crystals—turn out the final product on photo-sensitive paper." (Commun. ACM **9,** 467 (1966)).

"At International Business Machines Corp. . . . one method, devised for the Army Electronics Command, Fort Monmouth, N.J., makes use of a high-speed switching arrangement with electronically controlled crystals.

"Such a system could be used with a matrix containing alphabetical or other symbols. The laser would be used as a print-out device, projecting the various symbols onto a recording medium.

"The Air Force Systems Command at Wright-Patterson AFB is interested in IBM's work on a variable frequency laser which might be used in conjunction with a color-sensitive computer. This type of setup is said to have a potential capacity of a hundred million bits per square inch of photographic material." (Serchuk, 1967, p. 34).

6.25 "Instead of recording a bit as a hole in a card, it is recorded on the file as a grating pattern of a certain spacing . . . A number of different grating patterns with different spacings can be superposed and when light passes through, each grating bends the light its characteristic amount, with the result that the pattern decodes itself . . . The new system allows for larger areas on the film to be used and lessens dust sensitivity and the possibility of dirt and scratch hazards." (Commun. ACM **9,** No. 6, 467 (June 1966).)

6.26 "Recently Longuet-Higgins modeled a temporal analogue of the property of holograms that allows a complete image to be constructed from only a portion of the hologram. In the present paper a more general analogue is discussed and two two-step transformations that imitate the recording-reconstruction sequence in holography are presented. The first transformation models the recall of an entire sequence from a fragment while the second is more like human memory in that it provides recall of only the part of the sequence that follows the keying fragment." (Gabor, 1969, abstract, p. 156).

6.27 "A new recording mechanism . . . consists of the switching of magnetization under the influence of a stress resulting from a heat gradient introduced by a very narrow light or electron beam. The mechanism is assumed to be magnetostriction with a rotation of the anisotrophy. The model presented and the criteria for recording are supported, at least in part, by experimental observations." (Kump and Chang, 1966, p. 259).

6.28 "In attempts to provide computers with previously unavailable amounts of archival (read-only) storage, various techniques involving optical and film technology have been employed to utilize the high information capacity of film (approximately 10^6 bits/in.^{2}) and the high resolution and precision of lasers and electron beams. The trillion-bit IBM 1350 storage device, an offshoot of the 'Cypress' system, . . . uses 35 mm×70 mm silver halide film 'chips.'

"A total of 4.5 million bits are prerecorded on each chip by an electron beam. For readout, a plastic cell containing 32 film chips is transported to a selector, which picks the proper chip from among the 32; average access time to any of the 10^{12} bits is 6 seconds. After a chip is positioned, information is read using a flying-spot CRT scanner.

Two IBM 1350 units are scheduled for mid-1967 delivery to the Atomic Energy Commission at Livermore and at Berkely for use with bubble chamber data. Other techniques of reading and writing with electron beams are explained by Herbert." (Van Dam and Michener, 1967, p. 205).

6.29 "Results of basic theoretical studies conducted at the NCR research laboratories have indicated that CW lasers of relatively low power should be capable of permitting very high resolution real-time thermal recording on a variety of materials in the form of thin films on suitable substrates. Subsequent laboratory studies have shown that such thermal recording is indeed possible. This recording technique has been termed heat-mode recording." (Carlson and Ives, 1968, p. 1).

"The recording medium is coated on a 5- by 7-inch glass plate, a quarter of an inch thick. The plate carrier mechanism is capable of stepping in the horizontal and vertical directions to form matrices of up to 5,000 images at an overall reduction of 150 to 1." (Carlson and Ives, 1968, p. 5).

"The results of the studies described in this paper have established laser heat-mode recording as a very high resolution real-time recording process capable of using a wide variety of thin film recording media. The best results were obtained with images which are compatible with microscope-type optics. The signals are in electronic form prior to recording and can receive extensive processing before the recording process occurs. In fact, the recordings can be completely generated from electronic input. For example, Figure 6 shows a section of a heat-mode microimage with electronically generated characters, produced by the Engineering Department in our Division. The overall image is compatible with the 150-to-1 PCMI system (less than 3 mm field), and consists of 73 lines of characters, 128 characters per line. Although this image was recorded in 1.6 seconds, faster recordings are anticipated. A description of this work will be published in the near future." (Carlson and Ives, 1968, p. 7).

6.30 "Another scheme for storing digital information optically is the UNICON system, under development at Precision Instrument Company. This system uses a laser to write 0.7-micron-diameter holes in the pigment of a film. Information is organized in records of at most a million bits; each record is in a 4-micron track extending about a meter along the film. Individual tracks are slanted slightly so that they extend diagonally across the film. (The amount of slant and the width of the film determine the length of the records.) Each record is identified by information stored next to the beginning of that record, in an additional track at the edge of the film. Readout of a particular record involves scanning the identifier track for the proper code and then scanning the track with a laser weaker than that used for writing. It is predicted, on the basis of an experimental working model, that one UNICON device with 35 mm film could store a trillion bits on 528 feet of film, with an average access time to a record of 13 seconds." (Van Dam and Michener, 1967, p. 205). (See also note 6.14).

6.31 "Considerable experimentation in modulation and transmission is needed before optical communication by laser can be said to be really useful except in very specialized cases." (Bloom, 1966, p. 1274).

6.32 "At first sight a laser communication system with its extremely wide information carrying capacity would appear to be a natural choice for an interplanetary communication system. However, among other things, the acquisition and tracking problems are considered to be so severe that such a system is not thought to be realistic at the present time. This may be indicative of an information technology utilization gap." (Asendorf, 1968, p. 224).

6.33 "In general, earthbound laser-ranging systems are limited by local atmospheric conditions. A typical value of range routinely measured is 20 km or less." (Vollmer, 1967, p. 68).

"Earthbound applications of coherent optical radiation for communications appear to be severely limited for two reasons. The first, and most significant, is the effect of atmospheric turbulence on the coherence of the radiation. The second is the effect of small vibrations on the coherent detection efficiency and signal-to-noise ratio. This can be minimized by careful design, but the first factor is beyond the designer's control. Although coherent optical detection has been demonstrated over some useful paths, the vulnerability of the link to atmospheric variations makes practical application somewhat doubtful." (Cooper, 1966, p. 88).

6.34 "Is the enormous increase in bandwidth offered by light as a carrier frequency in communications needed? For transmission in space the acquisition and aiming of the light beams pose formidable problems. In the atmosphere, rain, smog, fog, haze, snow, etc., make light a poor competitor of microwaves. Can a system of enclosed tubes with controlled atmosphere and light repeater stations be built on a technologically sound and economically feasible basis?" (Bloembergen, 1967, p. 86).

6.35 "Information Acquisition, Sensing, and Input", Sect. 3.1.1. Some additional references are as follows:

"Since the first laser was demonstrated in 1960, considerable interest has developed in its possibilities for use in communication systems. The basic sources of this interest are the coherent nature of the radiation obtained as compared with all previously known extended sources of optical radiation, and the laser's short wavelength. This latter characteristic provides the potential ability to achieve bandwidths, or information capacities, that are orders of magnitude greater than anything obtained heretofore. A more realistic advantage, in terms of presently available information sources, results from the combination of high coherence and short wavelength. It is the ability to generate a highly collimated beam (limited by diffraction phenomena), which leads to the ability to achieve communications over great distances. Of equal importance is the fact that with a coherent signal, coherent detection of the information can be obtained with greatly improved immunity to natural incoherent noise sources such as the sun." (Cooper, 1966, p. 83).

"The first enthusiastic suggestions that laser technology potentially provides many orders of magnitude more communication capability than RF technology, and that it might, therefore, offer the only solution to the problem of general wideband communications with deep-space probes, needs to be more carefully assessed." (Dimeff et al., 1967, p. 104).

"For deep-space, wide-band communication . . . another factor may be . . . important—namely, the size of the transmitting aperture. A very large aperture, as would undoubtedly be required by a microwave channel, is likely to prove an obstruction to the sensors of the aircraft and will, therefore, reduce the time available for collecting information or transmitting it. In this respect, the laser has an important advantage over microwave." (Brookner et al., 1967, p. 75).

"Several optical links which use GaAs injection lasers as transmitters have been constructed. One of them has been demonstrated to be capable of transmitting 24 voice channels over 13 km." (Nathan, 1966, p. 1287).

6.36 "If we classify our communication requirements on the basis of range, we find that lasers can be helpful at the range extremities—that is, for distances less than about 15 km and for those greater than 80 million km." (Vollmer, 1967, p. 66).

6.37 "An electronic system that transmits military reconnaissance pictures from Saigon to Washington in minutes via satellite may soon enable news media to dispatch extremely high-quality photographs and type around the world for instant reproduction.

"Potential benefits are also foreseen for medicine, earth resources surveys and industry.

"The high-performance system was developed for the U.S. Air Force Electronics Systems Divisions by CBS Laboratories, a division of Columbia Broadcasting System, Inc. It combines electro-optical and photographic techniques to relay high-resolution aerial photographs of ground activity in Vietnam to the President and Pentagon officials. Pictures seen by the President are many times sharper than the best pictures shown on home television sets.

"Within minutes after photographs have been taken in Vietnam, they are readout by the system's electronic scanning device and converted to video signals. The signals are then fed to a communication link, which relays them over the U.S. Defense Satellite Network to Washington. A similar receiving and recording station there reconstructs the photographs to their original form for immediate inspection." (Spie Glass **5**, No. 2, 9 (Aug. 1969).)

"According to Air Force officials, pictures produced by the CBS Laboratories Image Scanning and Recording System contain the highest resolution ever reported in the transmission of aerial reconnaissance photographs. High-altitude photographs processed by the system show such detailed information as identification numbers of ships in port, planes on runways and troop movements . . .

"In operation, the lightweight system uses a precisely controlled laser beam to scan rapidly across photographic film. The laser converts each picture frame to an electronic video signal. The signal is then fed to a transmitting device for satellite relay, said John Manniello, CBS Laboratories Vice President for Government Operations, who conceived the system application. Once the signals contact the satellite, they are flashed to a receiving station in Washington within seconds, he added.

"The receiving station—which has related photo-scanning, recording and developing equipment—reconstructs the video signal to the original film image and produces high-quality photographic prints.

"Because of the laser-scanning technique involved, no photographic resolution is lost between recording and transmission from the original film taken in Vietnam." (Spie Glass **5**, No. 2, 9 (Aug. 1969).)

6.38 "Superficially, it appears attractive to have fast switching, high storage density, direct visual display. Such developments would depend heavily on the availability of cheap, small, high-quality semiconductor lasers. If these were available, the entire organization of computers using them would probably be different." (Bloembergen, 1967, p. 86).

6.39 "The power and efficiency available from lasers at the desired wave lengths (particularly ultraviolet) must be improved, and adequate laser deflection techniques must be developed before laser displays will be feasible for widespread use." (Hobbs, 1966, p. 1882).

"Since lasers don't require vacuums, there is a significant convenience relative to electron beams. But there is a severe penalty compared to electron beams due to problems in deflecting, modulating, and focusing." (Gross, 1967, pp. 7–8).

"Lasers offer great promise for future implementation of display systems—particularly large-screen displays. The ability of a laser to deliver highly concentrated light energy in a coherent beam of very small spot size is well known. Several different approaches to laser displays are being investigated. Since they all require some means for deflecting and modulating the laser beam, considerable development efforts are being expended on deflection techniques. Digital deflection of lasers by crystals has been satisfactorily demonstrated for 256 positions in each direction, but at least 1024 positions in each direction are needed for a practical large-screen display system." (Hobbs, 1966, p. 1881).

"The laser is an efficient light source, and its output can be focussed to small sizes and high power densities. There is confidence that laboratory means for modulating lasers and deflecting their beams will be found practical." (Bonn, 1966, p. 1869).

"More rapid progress would be made in utilizing laser recording if better means of deflecting laser beams at the desirable speeds and resolutions existed or were clearly foreseeable." (Smith, 1966, p. 1297).

"An experimental device that can switch the position of a light beam more than a thousand times faster than the blink of an eye could become an important part of computer memories of the future. The device, a digital light deflector, was developed at the IBM Systems Development Div. laboratory in San Jose, Calif.

"The experimental deflector changes the location of a beam in 35 millionths of a second by a unique method of moving a glass plate in and out of contact with a prism.

"High-speed deflectors of this type are potentially useful in future optical memories to randomly position a laser beam for data recording and reading. Such beam addressable memories are expected to be many times faster than present magnetic storage methods because of the relative speed of relocating a light beam in comparison to moving a bulky recording head." (Computers & Automation **18,** No. 5, 68 (May 1969).)

6.40 "Another attractive approach is the use of a laser beam to write directly on a large luminescent screen. This is somewhat equivalent to an 'outdoor' cathode-ray tube in which the laser beam replaces the electron beam and the luminescent screen replaces the phosphor face plate of the tube. It offers advantages over a CRT in that a vacuum is not required and a large-screen image can be generated directly. One feasibility system has been developed using a 50 milliwatt neon-helium gas laser, a KDP crystal modulator, a piezoelectric crystal driven horizontal deflecting mirror, and a galvanometer driven vertical deflecting mirror to provide a television rastor scan image projected onto a 40 inch screen. Brightness of 50 foot-lamberts, contrast ratio of 100 to 1 (dark environment), resolution of 1,000 to 2,000 lines, and update time of 33 milliseconds are anticipated for direct view laser systems." (Hobbs, 1966, p. 1882).

6.41 "Electron-beam devices, including those which use photographic emulsions and thermoplastic films, operate in a vacuum, which is a nuisance." (Bonn, 1966, p. 1869).

6.42 "By definition, phototropy is the photochemical phenomenon of changing some physical property (color) on exposure to electromagnetic radiation (light) and returning to its original (colorless) state after removal of the activating source and under a de-activation condition and/or at a later time." ("Investigation of Inorganic Phototropic Materials . . .", 1962, p. 1).

"The property of certain dyes and other chemical compounds to exhibit a *reversible* change in their absorption spectrum upon irradiation with specific wavelengths of light has been termed *phototropism*, or *photochromism*. The emphasis in this definition is on *reversibility*, because, upon removal of the activating radiation the systems must revert to their original states to be considered photochromic." (Reich and Dorion, 1965, p. 567).

"By definition, photochromic compounds exhibit reversible spectral absorption effects—color changes, resulting from exposure to radiant energy in the visible, or near visible, portions of the spectrum. For example, one class of photochromic materials consists of light-sensitive organic dyes. NCR photochromic coatings consist of a molecular dispersion of these dyes in a suitable coating material. Photochromic coatings are similar to photographic emulsions in appearance and with respect to certain other properties. Coatings can be made to retain two-dimensional patterns or images which are optically transferred to their surface." (Hanlon et al., 1965, p. 7).

"Photochromic film, a reusable UV sensitive recording media has progressed to the point where prototype equipment is being designed." (Kesselman, 1967, p. 167).

6.43 "Photochromic coatings exhibit excellent resolution capabilities. In addition, both positive-to-negative and direct-positive transfers are possible . . . The coatings are completely grain-free, have low gamma (excellent gray scale characteristics), and exhibit inherently high resolution . . . Further, because the coatings are reversible, the information stored can be optically erased and rewritten repeatedly." (Hanlon et al., 1965, p. 7).

"Photochromism may be defined as a change in color of a material with radiation (usually near ultraviolet) and the subsequent return to the original color after storage in the dark. Reversible photochromism is a special case of this phenomenon in which a material can be reversibly switched by radiation between two colored states. Photochromic compounds may be valuable for protection from radiation; reversibly photochromic materials are potentially valuable for data storage and display applications." (Abstract, talk on photochromic materials for data storage and display, by U. L. Hart and R. V. Andes, UNIVAC Defense Systems Division, at an ONR Data Processing Seminar, May 4, 1966, See also Hart, 1966).

6.44 "Most of the systems so far reported are only partially, or with difficulty, reversible, or are subject to fatigue—a change in behavior either with use or with time in storage." (Smith, 1966, p. 40).

"Organic photochromic materials fatigue with use." (Bonn, 1966, p. 1869).

6.45 "Photochromic films permit the storage of images containing a wide contrast of gray scale because they are inherently low gamma and grain-free." (Tauber and Myers, 1962, p. 409).

6.46 "It is recorded that Alexander the Great discovered a substance, whose composition has been lost in the obscurity of antiquity, that would darken when sunlight shone upon it. He dipped a narrow strip torn from the edge of his tunic into a solution of the material and wore this strip wrapped about his left wrist. Many of his soldiers did the same. By observing the changes of color during the day, they could tell the approximate hour. This became known as Alexander's rag time-band. (I am sorry that I cannot identify, and hence cannot give proper credit to the author of this delightful footnote to history.)" (Smith, 1966, p. 39).

6.47 "1. Photochromic films provide very high resolution with no grain.

"2. Photochromic films permit the storage of images containing a wide contrast of gray scale because they are inherently low gamma and grain-free.

"3. Photochromic films provide immediate visibility of the image upon exposure. No development process is required.

"4. Photochromic films provide both erasing and rewriting functions. This permits the powerful processes editing, updating, inspection, and error correction to be incorporated into systems.

"5. The PCMI process incorporates the ability to effect a bulk-transfer read-out of micro-images at the 200:1 reduction level by contact printing.

"6. Use of high-resolution silver halide films provides both permanency for the storage of micro-images and economical dissemination of duplicates.

"7. The very high density of 200:1 micro-images offers the possibility of using some form of manual retrieval techniques for many applications. This eliminates the normal requirement in systems of this size for expensive and complex random access hardware." (Tauber and Myers, 1962, p. 266).

In the photochromic micro-image (PCMI) micro-form process developed by the National Cash Register Company there have been achieved "linear reductions from 100-to-1 to greater than 200-to-1, representing area reductions from 10,000-to-1 to greater than 40,000-to-1, [which] have been successfully demonstrated by using a variety of image formats, such as printed materials, photographs, drawings, and even fingerprints." (Hanlon et al., 1965, p. 1).

"NCR has developed a number of research prototype readers for viewing PCMI transparences . . . [including] a miniaturized microimage reader . . . which was designed specifically for possible use aboard a manned space vehicle. The reader would have a self-contained, fixed reference file of up to 50,000 pages of information, such as navigational charts, planetary and space data, and checkout, maintenance, and emergency procedures." (Hanlon et al., 1965, p. 13).

"Current design emphasis by NCR has been toward the development of low cost PCMI readers for commercial applications." (Hanlon et al., 1965, p. 19).

6.48 "The information glut threatening to swamp the engineer and the scientist is being eased by a British organization called Technical Information on Microfilm. The medium of the 'message' is the National Cash Register Company's PCMI process. This makes possible the storage of over 3000 printed pages of information on a single 4-by-6-inch transparency. The system used by TIM enables the engineer to locate the data he wants in a matter of seconds. He simply selects the proper transparency and immediately locates the appropriate page images with an NCR reader which displays the selected pages on an illuminated viewing screen. TIM points out that one of the most valuable sources of information to engineers and scientists is manufacturers' literature. The problem has been that this is produced in an extraordinary variety of forms. These are difficult to catalogue comprehensively and they also create an enormous bulk. The NCR-developed PCMI technology involves a photochromic coating which produces an image that is virtually grain-free. The process permits a microscopic-size reduction which is not practical with conventional microfilm processes. NCR is producing the transparencies for TIM in its Dayton, Ohio processing center from 35-millimeter microfilm supplied by the British firm. All data is updated every six months." (bema News Bull., Dec. 9, 1968, p. 8).

6.49 "Information stored on photochromic coatings is semipermanent . . . This is a result of the reversible nature of the photochromic coating. The life of the photochromic micro-image is dependent upon the ambient temperature of the coating. At room temperature, image life is measured in hours, but as the temperature is lowered, life can be extended very rapidly to months, and even years." (Hanlon et al., 1965, p. 8).

6.50 "The temperature-dependent decay of image life obviously prohibits the use of photochromic micro-images in their original form for archival storage. To overcome this problem, means have been developed for contact-printing the photochromic micro-images to a high-resolution photographic emulsion, thereby producing permanent micro-images." (Hanlon et al., 1965, pp. 8–9).

"The entire contents of the photochromic micro-image plate are then transferred (as micro-images) in one step, by contact-printing onto a high-resolution silver halide plate . . . Micro-image dissemination (duplicate) films are prepared in a similar manner, using the silver masters to contact-print onto high-resolution silver halide film." (Hanlon et al., 1965, p. 9).

6.51 Further, "a more realistic assessment . . . so that spillover, halation, and registration restrictions would not be impossibly severe, still results in a contiguous bit density of $10^6/cm^2$." (Reich and Dorion, 1965, p. 572).

6.52 "Transparent silicate glass containing silver halide particles darkens when exposed to visible light, and is restored to its original transparency when the light source is removed. These glasses have been suggested for self-erasing memory displays, readout displays for air traffic controls, and optical transmission systems. . . .

"Photochromic glass appears to be unique among other similar materials because of its non-fatiguing characteristics. No significant changes in photochromic behavior have resulted from cycling samples with an artificial 3600Å black light source up to 30,000 cycles. There were also no apparent solarization effects causing changes in darkening or fading rates after accelerated UV exposure equivalent to 20,000 hours of noon-day sunshine." (Justice and Leibold, 1965, p. 28).

"Another potentially important application of photochromic materials is in the display of information. Data can be recorded in photochromic glass in two ways: by darkening the glass with short-wavelength light in the desired pattern; or by uniformly darkening the glass and bleaching it, in the desired pattern, with longer wavelength light." (Smith, 1966, p. 45).

6.53 "To produce a display, patterns of varying optical density are written on photochromic film with a deflected ultraviolet light beam. The film so exposed forms the 'object' in a projection system. Visible light is projected through the film onto a screen. This display has mechanical simplicity, controllable persistence, and a brightness comparable to conventional film-projection displays." (Soref and McMahon, 1965, p. 62).

6.54 "For dynamic applications such as target tracking, this technique not only permits a real-time target track, but also provides target track history in the form of a trace with 'intensity' decreasing with time. The time period covered by the visible target track history is a function of the photochromic material. At the present time, the speed of photochromic materials limits the character generation rate to less than 100 characters per second. Successful development of faster photochromic materials will provide an attractive electro-optical dynamic large-screen display with no mechanically moving parts." (Hobbs, 1966, p. 1879).

6.55 "One of the technological trends which will give us mass memories at a viable price is photochromic microimagery. Photochromic techniques—by which as many as 2,000,000 words can be stored on a film transparency only 4 inches by 6 inches—can now be used to store a pattern of bits instead of images of pictorial or alphabetical information. Photochromic high-resolution films coupled with proper light sources and optical systems can provide the storage of millions of bits to the square inch. A micro-holographic indexing system used with such storage devices may revolutionise data storage and retrieval." ("R and D for Tomorrow's Computers," 1969, p. 53).

6.56 "The breadth of the sensitivity characteristics of the photochromic films in conjunction with the width of the spectral characteristics of the available phosphors present a potential systems designer with a choice of a number of component parts . . . Future improvements in CRT-photochromic film display systems are dependent upon the capabilities of each of the components. The basic parameters which enter into the cathode ray tube efficiency are the fiber optic plate and phosphor. An increase in the fiber optic efficiency is doubtful except through the use of higher numerical aperture fibers. Increasing the numerical aperture has the disadvantage of requiring a higher degree of control on the film-CRT gap. An improvement in basic phosphor efficiency is difficult to foresee although several military agencies are now or will be sponsoring programs to achieve this goal.

"An advance of the state-of-the-art of phosphor technology should be possible by a factor of 4, but probably not beyond. By careful optimization of the phosphor deposition with respect to particular applications some improvement is possible. At the same time an increase in the efficiency of the photochromic film by a factor of 2 is theoretically possible. Of more importance to the system designer is the understanding and optimization of writing and rewriting rates as they affect phosphor efficiency and life and in the matching of the CRT with the photochromic film." (Dorion et al., 1966, p. 58).

6.57 "Wavefront reconstruction was invented by Gabor and expounded by him in a series of classic papers [1948–1951]." (Armstrong, 1965, p. 171).

"The wavefront reconstruction method of image formation was first announced by Gabor in 1948."

6.58 Stroke gives a derivation of the term: "Hence, the name 'hologram' from the Greek roots for 'whole' and 'writing'." (Stroke, 1965, p. 54). And also defines it: "A hologram is therefore an interference pattern between a reference wave and the waves scattered by the object being recorded." (Stroke, 1965, p. 53).

6.59 See also the following:

"Arbitrary objects . . . are illuminated by parallel laser light. In the general case, the light reflected by these objects will be diffuse and the reflected wavefronts will proceed to interfere in the photosensitive medium where the interference pattern can be recorded. After the photosensitive medium has been exposed and processed it is called the *hologram*, which may be defined as the recorded interference of two or more coherent wavefronts. When the hologram is illuminated by one of the *original* wavefronts used to form it, the remaining wavefronts are reconstructed . . . Observation of these reconstructed wavefronts is nearly equivalent to observing the objects from which they were originally derived." (Collier, 1966, p. 67).

"An optical hologram is a two-dimensional photographic plate which preserves information about the wavefront of coherent light which is diffracted from an object and is incident upon the plate. A properly illuminated hologram yields a three-dimensional wavefront identical to that from the original object, and thus the observed image is an exact reconstruction of the object. The observed image has all of the usual optical properties associated with real three-dimensional objects; e.g., parallax and perspective." (Lesem et al., 1967, p. 41).

6.60 "Holography is the science of producing images by wavefront reconstruction. In general no lenses are involved. The reconstructed image may be either magnified or demagnified compared to the object. Three-dimensional objects can be reconstructed as three-dimensional images." (Armstrong, 1965, p. 171).

6.61 "Are Holograms Already Outdated? Holography is one of the most exciting developments of today's technology. Holograms make use of a high-energy laser beam to store or display three-dimensional images for such applications as read-only storage; packing densities and device speeds are extremely impressive. However, at today's pace of innovation, holography may be outmoded before it approaches being practical. One of the latest competitors for 3-D display, storage, and wave conversion applications is the kinoform, a new wavefront reconstruction device which also projects a 3-D image, but requires one-fourth of the computer time to generate and creates images roughly three times as bright.

"A computer program is used to produce a coded description of light being scattered from a particular object. The resultant computations are used to produce a 32-grey-level plot which is photoreduced and bleached. Then, when subjected to even a very small light source, such as the girl's earring in the photo above, the 3-D image is formed. A kinoform image can be produced of any object which can be computer-described. Examples might include proposed buildings, auto designs, relief maps, or two-dimensional alphanumeric data." (Datamation **15**, No. 5, 131 (May 1969)).

6.62 "The kinoform is a new, computer-generated, wavefront reconstruction device which, like the hologram, provides the display of a three-dimensional image. In contrast, however, the illuminated kinoform yields a single diffraction order and, ideally, all the incident light is used to reconstruct this one image. Similarly, all the spatial frequency content or bandwidth of the device is available for the single image. Computationally, kinoform construction is faster than hologram construction because reference beam and image separation calculations are unnecessary.

"A kinoform operates only on the phase of an incident wave, being based on the assumption that only the phase information in a scattered wavefront is required for the construction of an image of the scattering object. The amplitude of the wavefront in the kinoform plane is assumed constant. The kinoform may therefore be thought of as a complex lens which transforms the known wavefront incident on it into the wavefront needed to form the desired image. Although it was first conceived as an optical focusing element, the kinoform can be used as a focusing element for any physical waveform, e.g., ultrasound or microwaves." (Lesem et al., 1969, p. 150).

6.63 "A new hologram made at Bell Telephone Laboratories now allows the viewer to see a 3D image rotate through a full 360 degrees as he moves his head from side to side . . . To make a flat hologram with a 360-degree view, vertical strips of the photographic plate are exposed sequentially from left to right across the plate. A narrow slit in a mask in front of the plate allows only one strip to be exposed at a time, each strip becoming a complete hologram of one view of the object." (Data Proc. Mag. **10**, No. 4, 16 (Apr. 1968)).

6.64 "Holography provides an alternative description of pictures, which might be more amenable to bandwidth compression. To investigate this possibility, it is desirable to measure various statistics of the hologram, and to try various operations on it to see what their effects would be on the reconstructed pictures. . . . Holography and other coherent optical processing . . . techniques have made possible relatively simple ways of obtaining the Fourier transforms of two-dimensional functions and operating on them in the frequency domain." (Quarterly Progress Report No. 81, Research Laboratory for Electronics, M.I.T., 199 (1966)).

6.65 "Gabor and others have proposed the use of the wavefront reconstruction method to produce a highly magnified image, using either a change in wavelength between recording of the hologram and its reconstruction, or by using diverging light for one or both steps of the process. The two-beam process is readily amenable to such magnification . . ." (Leith et al., 1965, p. 155).

6.66 "Color reconstructions should be attainable from black and white holograms if suitable temporal coherence conditions are ensured." (Stroke, 1965, p. 60).

"Holography is another field for which the laser has opened many possibilities. Perhaps it will find useful applications in pattern recognition and in storage of three-dimensional information as a Fourier transform. . . .

"Three-dimensional displays of airfield approaches in the cockpit of a jet liner with the correct viewing angle from the position of the aircraft would be a more interesting application [of laser-holographic recordings]." (Bloembergen, 1967, p. 86).

"We read about images having three-dimensional properties, magnification obtained by reconstructing with a wavelength greater than that used in forming the hologram, diffuse holograms which, even when broken, produce whole images, multicolor images obtaining from emulsions which normally produce only black and whites." (Collier, 1966, p. 67).

"The recording of surface deformations in engineering components demonstrated here shows how these techniques may be applied at low cost and in a short time. For teaching purposes it has been shown that interference holography of the distortions of a rajor blade can be demonstrated adequately to a large group of people in only a few minutes." (Bennett and Gates, 1969, p. 1235).

"With practical applications for holograms still in the few-and-far-between stage, the Office of Naval Research and IBM believe they have a holographic application that is both practical and unique: in a head-up, all-weather landing system.

"The system—now at the laboratory model stage—employs a hologram of an aircraft carrier. The hologram is picked up by an infrared vidicon and projected on a crt cockpit display . . .

"The achievement is one of application in which a two-dimensional representation with the so-called six degrees of freedom encountered in a carrier landing, and full ranging capability, is produced without employing a computer. The demonstration model simulates an approach window two miles wide and a half-mile high and offers a 3.5-degree glide slope. The six degrees (glide-slope deviation, localized deviation, depression angle, bearing angle, roll, and slant angle) are achieved mechanically, electronically, and optically. For example, roll is achieved as the vidicon itself is rolled; glide-slope deviation is simulated by manipulating the hologram. In the model, the generated image allows a view which includes magnification of the holographic image of the carrier up to 16-to-1 and permits views including one below the deck of the carrier." (Electronics **42**, No. 13, 46 (June 23, 1969).)

"General Electric has also examined the hologram for potential in character recognition. One method suggested by GE is to create a spatial filter using a hologram. This filter can be used to detect, or recognize, specific shapes from among a random assortment.

"This general scheme is the basis for a personnel identification system being developed by National Cash Register Co., Dayton, Ohio.

"According to NCR, two of the most important aspects of identification are signatures and photographs. In the NCR system, a hologram containing signatures and numbers randomly located is placed in the optical path of a laser.

"If matching occurs when a signature card is inserted into a receiving device, the system locates the picture [which] is projected for comparison." (Serchuk, 1967, p. 34).

6.67 "The wavefront reconstruction method offers the possibility of extending the highly developed imagery methods of visible-light optics to regions of the electromagnetic spectrum where high-quality imagery has not yet been achieved . . ." (Leith et al., 1965, p. 157).

6.68 "A Megabit digital memory using an array of holograms has been investigated by Bell Laboratory scientists. The memory is semipermanent, with information being stored in the form of an array of holograms, each hologram containing a page of information. A page is read . . . by deflecting a laser beam to the desired element of the array, so as to obtain reconstruction of the image stored in the element—the digital information—on a read-out plane which is common to all elements of the array. Photosensitive semiconductors arrayed on the read-out plane then sense the stored information . . .

"In the Bell Labs experimental system, the light source is a continuous-wave helium-neon laser operating in the lowest order transverse mode. Two-dimensional deflection is accomplished by cascaded water-cell deflectors, using Bragg diffraction from ultrasonic waves in water, and capable of deflecting the beam to any of 300 addresses in less than 15μsec . . .

"The present system comprises 6 k bits per page, and a 16 × 16 matrix of pages, for a total capacity of 1.5 M bits access time is 20 μsec. Total optical insertion loss is 75 db, resulting in 70 k photons impinging on each bit detector . . . and Bell Labs scientists project that, by straightforward extensions of the present system, 25 M bits with an access time of 7 μsec is a feasible system. This system would have 65 × 65 matrix of 6 k bit pages, a faster deflection system, and a reduced insertion loss of 65 db, resulting in 0.5 M photons per bit at the detectors.

"Ultimately, it is predicted that a memory can be built having greater than 100 million bits of storage, with an access time in the one microsecond range." (Modern Data Systems **1**, No. 2, 66 (Apr. 1968).)

"Bell Labs has already constructed a 'breadboard' hologram memory system . . . that may eventually be able to display any one of 100 million units of information upon one millionth of a second's notice.

"It is based on using a number of closely spaced holograms on a single photographic plate. Bell Labs had in mind switching operations as one fundamental application . . .

"This memory system works by directing a laser beam to one 'page' (location of a hologram) in an array. Initial goals are to make each hologram about a millimeter in diameter and to space them rather closely in a pattern of 100 rows by 100 rows. Each hologram will store, encoded in the form of an interference pattern, another 100 by 100 matrix. This will be coded in dots or blanks to represent information. The reconstructed hologram will be aligned precisely with an array of phototransistors (also under development at Bell Labs), which will 'report' to the electronic device which of the dots are present and which are absent. This roll call is the message." (Photo Methods for Industry **12**, No. 3, 61–62 (Mar. 1969)).

6.69 "Carson Laboratories, Bristol, Conn., for example is working on the development of potassium bromide and similar crystals as holographic materials.

"The laser is used to bleach the crystal in accordance with the holographic interference patterns. Such a memory device is said to have a capacity of 1 million bits per square half-inch of material." (Serchuk, 1967, p. 34).

6.70 "An experimental optical memory system that could lead to computer storage devices a thousand times faster than today's disk and drum storage units was reported . . . by three International Business Machines Corporation engineers.

"In the experimental system, blocks of information are accessed by a laser beam in just ten-millionths of a second. More than 100 million bits of computer information could be stored on a nine square inch holographic plate . . .

"The experimental memory system uses a laser beam to project blocks of information contained on the hologram onto a light-sensitive detector. The detector then converts the projected hologram into electronic signals which can be processed by a computer.

"In a feasibility model, assembled at IBM's Poughkeepsie, N.Y., Systems Development Division Laboratory, size, direction, and focus of the laser beam are determined by a series of lenses. The beam is positioned on the hologram by a crystal digital light deflector. By controlling the polarization of the light from the laser the deflector is used to select any block of information stored on a single plate.

"The hologram splits the laser beam into two separate rays: one non-functional and the other a first-order diffraction pattern which carries the holographic information. This first-order diffraction pattern is then focused on a light-sensitive detector array, which converts the optical information to electronic signals. The signals, representing data, are then sent to the computer's central processing unit at high speeds." (bema News Bull. 5, Nov. 18, 1968).

6.71 "An advantage of storing information in the form of a hologram rather than as a single real image is that the loss of data due to dust and film defects is minimized, since a single bit is stored not on a microscopic spot on the film but as part of an optical interference pattern which is contained in the entire hologram." (Modern Data Systems **1**, No. 2, 66 (Apr. 1968).)

"A bad spot in a photographic image will not spoil all bits of information completely; the Fourier transform of such a plate will still give a good image." (Bloembergen, 1967, p. 86).

"Since information from any one bit of the object is spread out over the whole hologram, it is stored there in a redundant form, and scratches or tears of the hologram make only a minor deterioration in the overall reconstructed image. In particular, no single bit is greatly marred by such damage to the hologram." (Smith, 1966, p. 1298).

"Leith reports that diffused illumination holograms have an immunity to dust and scratches and that particles have little effect in producing erroneous signals as in previous photographic memories." (Chapman and Fisher, 1967, p. 372).

"Since light from the point source is spread over the entire hologram's surface (thus ensuring interference patterns over the entire film surface), any part of the hologram will reproduce the same image as any other part of the hologram. It can be seen that the only effect of dust and scratches is to reduce the active area of the hologram." (Vilkomerson et al., 1968, p. 1199).

"Generally, the light projected into an image by a hologram is not associated with any specific point of the hologram, thus, if the hologram becomes marred by dust or scratches there is little degradation of any one point in the image. Dust and film imperfections can be a severe problem in non-holographic storage, because errors arise from the degradation of specific bits." (Gamblin, 1968, pp. 1–2).

6.72 Further, "the results of this study have indicated that holographic techniques are particularly suited to satisfy the functional requirements of read-only memory . . . Holography offers solutions to two key problems associated with the requirement for a single removable media storing up to 160,000 bits. First, the unique redundance inherent in holograms constructed with diffused illumination eliminates the loss of data due to such environmental effects as dust and scratches. Second, the potential freedom from registration effects which can be achieved by proper selection of construction techniques allows the manual insertion and removal of media with high bit packing densities and does not add a requirement for complicated mechanical positioning or complex electrical interconnection in the read unit." (Chapman and Fisher, 1967, p. 379).

6.73 "One can construct computer techniques which would take an acoustic hologram (the wavefront from a scattered sound wave) and transform it into an optical hologram, thereby allowing us to construct the three-dimensional image of the scatterer of the sound waves." (Lesem et al., 1967, p. 41).

6.74 "In a paper presented at the International Symposium on Modern Optics, researchers at the IBM Scientific Centre at Houston, Texas, described how they have programmed a computer—an IBM System/360 Model 50—to calculate the interference patterns that would be created if light waves were actually reflected from a real object. Neither the real object nor actual light waves are required to produce holograms with the computer technique. While the initial IBM computer hologram experiments have been restricted to two-dimensional objects for research simplicity, the authors said further work is expected to make possible digital holograms which can be reconconstructed into 3-D pictures. An engineer could then get a 3-D view of a bridge or car body design without actually building the physical object or even drawing it by hand." (The Computer Bull. **11**, No. 2, 159 (Sept. 1967)).

"More recently, firms have experimented with computer-generated holograms for unique data display. NASA's Electronics Research Center in Boston, Mass., is said to be investigating making real-time holograms for such applications as airport display to approaching aircraft.

"A team at IBM's Houston Scientific Research Center has programmed a System/360 Model 50 to create hologram by calculating the necessary interference patterns.

"Thus it may soon be possible to use the computer to create a mathematical model of a device and then translate equations into a three-dimensional hologram of the mathematical model." (Serchuk, 1967, p. 34).

6.75 "Holograms of three dimensional images have been constructed with a computer and reconstructed optically. Digital holograms have been generated by simulating, with a computer, the wave fronts emanating from optical elements, taking into account their geometrical relationship. We have studied in particular the effects of various types of diffuse illumination. Economical calculations of high resolution images have been accomplished using the fast finite Fourier transform algorithm to evaluate the integrals in Kirchoff diffraction theory. We have obtained high resolution three dimensional images with all the holographic properties such as parallax, perspective and redundancy." (Hirsh et al., 1968, abstract, p. H 104).

"Kinoforms serve for all of the applications of computer-generated holograms, e.g., three-dimensional display, wave conversion, read-only storage, etc. However, kinoforms give a more practical, computationally faster display construction that yields more economical use of the reconstructing energy and that yields only the desired image.

"The principal computational advantage of kinoforms as compared with digital holograms is embodied in the fact that all of the spatial frequency content of the device is used in the formation of the real image; none is required for the separation of the real and conjugate images. There is then at least a factor of four reduction in the computer time needed to calculate the wavefront pattern necessary for equivalent image quality. Correspondingly there is a reduction in plotting time for the kinoform.

"A further economy is achieved in that no calculations involving a reference beam are necessary. Finally, in the cases of one- and two-dimensional objects only real-number additions are required, once the basic transform is calculated, to determine the wavefront phase for plotting. The corresponding quantity to be plotted for digital holograms is the wavefront intensity which requires multiplication of complex numbers." (Lesem et al., 1969, p. 155).

6.76 "A[n] . . . important reason for synthesizing holograms is to create optical wavefronts from objects that do not physically exist. A need to form such a wavefront from a numerically described object occurs whenever the results of a three-dimensional investigation, for example, the analysis of an x-ray diffractogram must be displayed in three dimensions." (Brown and Lohmann, 1969, p. 160).

"Scientists, stock brokers, architects, statisticians and many others who use computers may soon have a practical, fast, and inexpensive way of converting memory data into three-dimensional pictures and graphs.

"With a process devised at Bell Telephone Laboratories, it takes only a few seconds of computer time to turn equations, formulas, statistical data and other information into a form suitable for the making of holograms. Viewed under ordinary light, the holograms produce three-dimensional pictures that can display a full 360-degree view of the object shown.

"Holography, which has been called 'lensless photography,' records a subject through the interference of two laser beams on a photographic plate. One beam is aimed directly at the plate, and the other reaches the plate after being transmitted through, or reflected by, the subject being 'photographed.'

"In the BTL method, the original subject exists only as a group of numbers or coordinate points in three dimensions, for example, in the computer's memory. The hologram is made in two steps. First, the computer is programmed to construct a series of two-dimensional pictures, or projections, each showing the 3-D data from a precisely defined unique angle. A microfilm plotter, connected to the computer, produces a microfilm frame for each picture.

"In the second step, a holographic transparency is made. The frames of the microfilm are used as subjects to make very small holograms (1 to 3 mm across), which are positioned sequentially on a holographic medium."

"Thus, a composite hologram is made up of a series of small holograms, each of which is formed with a two-dimensional image. But the composite image appears three-dimensional, and shows a

360-degree view of the object. With this type of hologram—also invented at BTL—the viewer can see the object rotating through a full cycle by simply moving his head from side to side in front of the hologram." (Computer Design **8**, No. 6, 28 (June 1969).)

6.77 "By the use of photographic recording techniques a very high information density can be achieved to which rapid random access can be made by appropriate electronic and optical techniques. If, therefore, there are any classes of information which must be read frequently, but are not *changed* for at least a week, then such a storage technique would be appropriate. This is evidently the case for all system programmes including compilers and monitor programs . . ." (Scarrott, 1965, p. 141).

"Photographic media are quite inexpensive, are capable of extremely high bit densities, and exhibit an inherent write-once, read-only storage capability. The optical read-out techniques, which are used, are nondestructive." (Chapman and Fisher, 1967, p. 372).

6.78 "To get an order of magnitude idea of the memory capacity, we will consider a memory plane of 2 in. square . . . There will be approximately 645 subarrays [individually accessible]. Consider that only one-half the memory plane is composed of active film. The memory would then contain almost 13 million bits." (Reich and Dorion, 1965, p. 579).

6.79 "The inherent power of optical processing can be exploited without suffering the speed limitations usually associated with static spatial filters. The method consists of using an electron beam-addressed electro-optic light valve (EOLV) as the spatial filter. Thus the filter need no longer be a fixed transparency, but can instead be a dynamic device whose orientation is controlled electronically rather than mechanically. This opens the method of optical processing to the domain of real time and presents exciting possibilities for its use in a variety of applications." (Wieder et al., 1969, p. 169).

6.80 "In optical transmission lines, the wavelength of the signals will be shorter than any of the circuit dimensions; therefore, one could eliminate, for example, all the reactive effects in the interconnections." (Reimann, 1965, p. 247).

"High-speed electronic computer circuitry is becoming interconnection limited. The reactance associated with the mounting and interconnections of the devices, rather than the response of the active components, is becoming the main factor limiting the speed of operation of the circuits.

"A possible approach to computer development that might circumvent interconnection limitations is the use of optical digital devices rather than electronic devices as active components." (Reimann, 1965, p. 247).

"One factor of growing significance, as circuit size is reduced, is the increasing amount of surface area consumed by areas devoted to interconnections and pads for interconnections. There have been marginal improvements over the past few years, but no startling improvements have been made in comparison to reductions in the basic device geometry.

"The consumption of real estate may be reduced by interconnecting the logic circuits with the narrow lines allowed by the masking technology, thus reducing to a minimum the area requirements for external lead pads. At this point, the semiconductor manufacturer relaxes and says in effect to the computer designer: Reduce your logic to a few standard configurations, and I will reduce costs by a large factor. Hence, we have a search for magic standard logic functions." (Howe, 1965, p. 507).

"Interconnections are already our problem for designing and building systems, and applying Large Scale Integration (LSI) to digital systems will inevitably force the realization that interconnections will be more important in determining performance than all other hardware factors. This is because the problems of physical size and bulk, DC Shift over long cables, reflections and stub lengths, crosstalk and RFI, and skin effect degradation are making computer systems interconnection limited." (Shah and Konnerth, 1968, p. 1).

6.81 "One example of these more exploratory attempts is the optically addressed memory with microsecond nondestructive read cycle and much longer write cycles. Chang, Dillon and Gianola propose such a *changeable* memory employing gadolinium iron garnets as storing elements." (Kohn, 1965, p. 133).

6.82 "Maintaining low power supply and distribution impedances in the presence of nanosecond noise pulses is an increasingly difficult problem . . . As more circuits are placed on a chip, decoupling of power supply noise will be required on or in close proximity to the chip." (Henle and Hill, 1966, p. 1858).

6.83 "Integrated circuitry has been widely held to be the most significant advance in computer technology since the development of the transistor in the mid-fifties . . . Semiconductor integrated circuits are microminiature circuits with the active and passive microcomponents on or in active substrate terminals. In thin-film integrated circuitry, terminals, interconnections, resistors and capacitors are formed by depositing a thin film of various materials on an insulating substrate. Microsize active components are then inserted separately to complete the circuit. Micromodules are tiny ceramic wafers made from semiconductive and insulative materials. These then function either as transistors, resistors, capacitors, or other basic components." ("The Impact . . .", 1965, p. 9).

6.84 "Integrated circuit technology will bring revolutionary changes in the size, cost, and reliability of logical components. Lesser improvements will be realized in circuit speed. . . .

"Advances in integrated circuit logic components and memories . . . will provide significant reductions in cost since the implementation of flexible character recognition equipment involves complex logical functions." (Hobbs, 1966, p. 37).

"Of course, the cost of electronics associated with peripherals will be drastically reduced by LSI. But the promise of LSI is greater than that. Functions that are now handled by mechanical parts will be performed by electronics. More logic will be built into terminals, and I/O devices such as graphic displays, in which the major cost is circuits, will come into more general use." (Hudson, 1968, p. 47).

"This speed power performance requires only modest advances from today's arrays. The board module size is convenient for small memory applications and indicates the method whereby LSI memories will establish the production volume and the impetus for main frame memory applications. The LSI memory being produced for the Air Force by Texas Instruments Incorporated falls into this category." (Dunn, 1967, p. 598).

"The Air Force contract [with Texas Instruments] has as a specific goal the achievement of at least a tenfold increase in reliability through LSI technology as compared with present-day integrated circuits." (Petritz, 1967, p. 85).

"Impetus for continued development in microelectronics has stemmed from changing motivations. Major emphasis was originally placed on size reduction. Later, reliability was a primary objective. Today, development of new materials and processes point toward effort to reduce cost as well as to further increase reliability and to decrease weight, cube, and power." (Walter et al., 1968, p. 49).

"This [LSI] technology promises major impact in many areas of electronics. A few of these are:

1. Lower cost data processing systems.
2. Higher reliability processing systems.
3. More powerful processing systems.
4. Incorporation of software into hardware, with subsequent simplification of hardware." (Petritz, 1966, p. 84).

"Computer systems built with integrated circuits have higher reliability than discrete-component machines. This improved reliability is due to two factors: (1) the silicon chip has a higher reliability than the sum of the discrete components it replaces, and (2) the high density packaging significantly reduces the number of pluggable contracts in the system." (Henle and Hill, 1966, p. 1854).

6.85 "One of the most interesting and significant paradoxes of the new technology is the apparent reconciliation of a desire to achieve high speed and low cost. The parameters which yield high speed, i.e., low parasitics, small device geometry, also yield lowest ultimate production cost in silicon integrated circuits." (Howe, 1965, p. 506).

6.86 "Some examples of functional expansion we would naturally consider are as follows. In the central processor LSI might be used to carry out more micro-operations per instruction; address more operands per instruction; control more levels of look-ahead; and provide both repetition and more variety in the types of functions to be executed. In system control, LSI might provide greater system availability through error detection, error correction, instruction retry, reconfiguration to bypass faulty units, and fault diagnosis; more sophisticated interrupt facilities; more levels of memory protection; and concurrent access to independent memory units within more complex program constraints. In system memory, LSI might provide additional fast local memory for operands and addresses; improved address transformation capability; content-addressable memory; and special fast program status tables. In system input-output, LSI might provide more channels; improved interlacing of concurrent input-output operations with automatic memory protection features; and more sophisticated pre- and post-processing of data and instructions to relieve the central processor of these tasks." (Smith and Notz, 1967, p. 88).

"LSI has an inherent functional advantage over magnetics in associative applications, namely that fast bit-parallel searches can be achieved. The main drawback of magnetic associative memories, even in those applications which require relatively simple match-logic per word, is that imperfect cancellation of analog sense signals and other noise effects give rise to a low signal-to-noise ratio and thereby limit the technology to essentially bit-serial operation. Thus, the more nearly binary signals available from semiconductor associative devices seem to provide a unique advantage over magnetics which is not strongly evident in comparisons of the two technologies over other categories of memory." (Conway and Spandorfer, 1968, p. 842).

"Content Addressable Memories: As the semiconductor manufacturer learns to produce more and more components on a single silicon chip, reasonably sized content-addressable memories may become feasible. Memories of this type, available on a large scale, should permit significant changes in the machine language of the computer, and possibly provide simplification in the design of such software as operating systems and compilers." (Graham, 1969, p. 104).

6.87 "Revolutionary advances, if they come, must come by the exploitation of the high degree of parallelism that the use of integrated circuits will make possible." (Wilkes, 1968, p. 7).

"One area in which I feel that we must pin our hopes on a high degree of parallelism is that of pattern recognition in two dimensions. Present-day computers are woefully inefficient in this area." (Wilkes, 1968, p. 7).

6.88 "The recent advance from discrete transistor circuits to integrated circuits is about to be overshadowed by an even greater jump to LSI circuitry. This new jump will result in 100-gate and then 1000-gate circuit modules which are little larger in size or higher in cost than the present four-gate integrated circuit modules." (Savitt et al., 1967, p. 87).

6.89 "Discrete components have given way to integrated circuits based on conventional etched circuit boards. This fabrication technique is in turn giving way to large scale integration (LSI), in which sheets of logic elements are produced as a unit." (Pyke, 1967, p. 161).

"The initial results suggest the possibility of fabricating, in one step, a complete integrated circuit with all the passive elements. Such a process would start with a metallized substrate and would use a programmable laser and work stage. Complete laser fabrication of hybrid circuits will require a process in which a metal film is removed selectively, exposing a different film. For example such a process may be necessary in order to remove the conductor and expose the resistor film.

"In the present tantalum-chrome-gold technology such a selective removal of the gold presents substantial difficulties because the reflectivity of the gold is much greater than that of the tantalum nitride. It is quite probable, however, that some combination of films will be found for which the upper film can be removed from the resistor without damaging it." (Cohen et al., 1968, p. 402).

6.90 "Integrated circuits (more importantly, large scale integration (LSI) which involves numerous integrated circuits tied together on the same chip) offer the best promise from the standpoint of size, reliability and cost [for scratch-pad memories]." (Gross, 1967, p. 5).

6.91 "Of all the potential applications of large-scale integration, new memory techniques are the most startling. Ferrite core memories have just about reached their limit in terms of access speeds required for internal scratchpads. Magnetic-thin films, while fast enough, are too costly. Studies show that because of LSI, semiconductor memories are less costly than any other approach for speeds from 25 to 200 nanoseconds and for capacities up to 20,000 bits—just the range required by scratchpads." (Hudson, 1968, p. 41).

6.92 "In addition to being used for circuitry, LSI techniques apply to the construction of memories, since some of the new memory elements mentioned above can be fabricated using the micro-construction techniques. The possibility also comes to mind of fabricating both the comparison circuitry and the memory cells of a content-addressable memory into a single unit. Thus the development of large-scale integration holds considerable promise for improving computer hardware." (Van Dam and Michener, 1967, p. 210).

6.93 "In view of the economy that should accompany widespread use of LSI, it may become less expensive to use LSI logic elements as main memory elements, at least for some portion of primary storage. Even today some systems have scratchpad memories constructed of machine logic elements, so that the fast processor logic is not held back by the slower memory capability." (Pyke, 1967, p. 161).

6.94 "LSI memories show considerable potential in the range of several hundred nanoseconds down to several tens of nanoseconds. In contrast with logic, LSI memory is ideally suited to exploit the advantages and liabilities of large chips: partitioning is straightforward and flexible, a high circuit density can be obtained with a manageable number of input-output pads, and the major economic barriers of part numbers and volume which confront LSI logic are considerably lower. Small-scale memory cell chips have already superseded film memories in the fast scratchpad arena; the depth of penetration into the mainframe is the major unresolved question." (Conway and Spandorfer, 1968, p. 837).

6.95 "As technological advances are made, the planar technology permits us to pack more and more bits on a single substrate thus reducing the interconnection problem and simplifying the total memory packaging job. This integration will reflect in the long run on product cost and product reliability." (Simkins, 1967, p. 594).

6.96 "The new technology has a number of problems whose solution can be facilitated by arranging the circuitry on these arrays in a 'cellular' form—that is, in a two-dimensional iterative pattern with mainly local intercell connections—that offers such advantages as extra-high packing density, ease of fabrication, simplified testing and diagnosis, ease of circuit and logical design, the possibility of bypassing faulty cells, and particularly an unusually high flexibility in function and performance." (Kautz et al., 1968, p. 443).

6.97 "LSI offers improvements in cost and reliability over discrete circuits and older integrated circuits. Improvement in reliability is due to the reduction of both the size and the number of necessary connections. Reductions in cost are due largely to lower-cost batch-fabrication techniques. One problem in fabrication is the increased repercussion of a single production defect, necessitating the discarding of an entire integrated component if defective instead of merely a single transistor or diode. This problem is attacked by a technique called discretionary wiring; a computer tests for defective cells in a redundantly constructed integrated array and selects, for the good cells, an interconnection pattern that yields the proper function." (Van Dam and Michener, 1967, p. 210).

"Since packaging and interconnections are major factors in the cost of an integrated circuit, the cost potentials . . . can be achieved only by batch fabricating large arrays of interconnected circuits in a single package. This raises many difficult and conflicting questions, such as packaging design, maintenance philosophy, flexibility and functional logic segmentation." (Hobbs, 1966, p. 39).

"The rapid and widespread use of integrated circuit logic devices by computer designers, coupled with further improvements in semiconductor technology has raised the question of the impact of Large Scale Integration (LSI) on computer equipment. It is generally agreed that this is a very complex problem. The use of Large Scale Arrays for logic require solutions to the problems such as forming interconnections, debugging logic networks, specifying and testing multistate arrays, and attempting to standardize arrays so that reasonable production runs and low per unit design costs can be obtained." (Petschauer, 1967, pp. 598–599).

"The advent of large-scale integration and its resultant economy has made it clear that a complete re-evaluation of what makes a good computer organization is imperative. Methods of machine organization that provide highly repetitive logical subsystems are needed. As noted previously, certain portions of present computers (such as successive stages in the adder of a parallel machine) are repetitive; but others (such as the control unit) tend to have unique nonrepetitive logical configurations." (Hudson, 1968, p. 42).

6.98 "Graceful performance degradation through use of majority voting logic.

"LSI will allow a single logical element to be replaced by several logical elements in a manner such that the elements can be used to determine the state or condition of a situation. The state or condition of the situation indicated by a majority of the elements can be accepted as valid—hence, majority voting logic." (Walter et al., 1968, p. 52.)

"Because of low cost modules, pennies and less per logic function, maintenance will be simplified and maintenance cost will be reduced by using throw-away modules. By 'wiring' the spares in, fabricated on the same LSI wafer that they are sparing, it becomes practical to self-repair a computer. This is accomplished by including diagnostic logic (coupled with programs) to effect the self-repair. Such a self-healing computer system, using electronic surgery, need only be manually maintained when its spare parts bank becomes exhausted. Some advantages of self-repair are:

- Increased system reliability
- Continuous operation (system always available)
- Long term (years) remote system operation without manual repair
- Considerable reduction in maintenance costs." (Joseph, 1968, p. 152).

6.99 See, for example, Rajchman (1965) and Van Dam and Michener as follows: "However, new memory elements, such as plated wires, planar thin films, monolithic ferrites, and integrated circuits, are becoming competitive. One advantage of these new elements is that a memory array made with them can be batch-fabricated in one step, leading to simpler, lower-cost production (the production of core memories requires making the magnetic cores and then stringing the cores together to make a memory). Another advantage appears to be in memory speed. The new memory elements have taken over the fields of high-speed registers and temporary 'scratch-pad' memories. Integrated circuitry . . . will probably replace the planar magnetic thin-film currently used for high-speed registers; however, the planar film will be extended to intermediate-sized stores (10^5–10^6 bits)." (Van Dam and Michener, 1967, p. 207).

6.100 "Today most common types [of core memories] have about a million bits and cycle times of about one microsecond, with bigger and faster types available. Capacity and speed have been constantly increasing and cost constantly decreasing." (Rajchman, 1965, p. 123).

"The ferrite core memory with 10^6 bits and 1μ sec cycle time is the present standard for main memories on the computer market. Larger memories up to 20.10^6 bits at 10μ sec cycle time have already been announced." (Kohn, 1965, p. 131).

"Ferrite cores dominated the main memory technology throughout the second generation. Most, although not all, of the third generation machines thus far announced have core memories." (Nisenoff, 1966, p. 1825).

6.101 "The NCR 315 RMC (Rod Memory Computer) has about the fastest main memory cycle time of any commercial computer yet delivered—800 nanoseconds. The unique thin-film memory is fabricated from hairlike berryllium-copper wires plated with a magnetic coating. In the Rich's system the 315 RMC processes data from over 100 NCR optical print cash registers . . ." (Data Proc. Mag. **7**, No. 11, 12 (1965)).

A later version of NCR's rod-memory computer, the 315–502, adds multiprogramming capability at an 800 nanosecond cycle time. (Datamation **12**, No. 11, 95 (Nov. 1966)).

"NCR's new thin-film, short-rod memory represents one of the most significant technical innovations in the Century series . . . The rods are made by depositing a thin metallic film and then a protective coating on 5-mil copper wire. This process yields a plated wire 0.006 inch in diameter, which is then cut into 0.110-inch lengths to form the 'bit rods'. The basic memory plane is formed by inserting the bit rods into solenoid coils wound on a plastic frame. Then the entire plane is sealed between two sheets of plastic. Automated processes are used to plate the wire, cut the rods, wind the solenoid coils, insert the rods into the solenoids, and seal the planes. The result is a high-performance memory at an unusually low bit cost." (Hillegass, 1968, p. 47).

6.102 For example, "laminate-diode memories of millions of bits operating in less than one microsecond seem possible in the near future." (Rajchman, 1965, p. 125).

"The cryotrons, the memory structure, and all connections are constructed by a single integrated technique. Thin films of tin, lead and silicon monoxide are evaporated through appropriate masks to obtain the desired pattern of lines. The masks are made by photoforming techniques and permit simple fabrication of any desired intricate patterns. . . .

"The superconductive-continuous sheet-cryotron-addressed approach to large capacity memory offers all the qualities, in its principle of operation and its construction, to support ambitions of integration on a grand scale as yet not attempted by any other technology. No experimental or theoretical result negates the promise . . . There is, however, a serious difficulty: The variation of the thresholds of switching between elements in the memory plane." (Rajchman, 1965, p. 127).

6.103 "A planar magnetic thin film memory has been designed and built by Texas Instruments using all integrated circuits for electronics achieving a cycle time faster than 500 ns, and an access time of 250 ns. The memory is organized as 1024 words by 72 bits in order to balance the costs of the word drive circuits against the sense-digit circuits. The inherent advantage of this particular organization is that the computer can achieve speed advantage not only because of a fast repetition rate, but also because four 18 bit words are accessed simultaneously. (Comparable core memory designs are ordinarily organized 4096 words of 18 bits each.) The outlook is for higher speed (faster than 150 ns) memories in similar organizations to be developed in planar magnetic films. The cost of these memories will be competitive with 2-1/2 D core memories of the same capacity but the organization and speed can be considered to offer at least a 4 : 1 improvement in multiple word accessing and a 3 : 1 improvement in speed. As a result of this, more computers will be designed to take advantage of the long word either by extending the word length of the computer itself or by ordering instructions and data in such a manner that sequential addressing will be required a large percentage of the time." (Simpson, 1968, pp. 1222–1223).

6.104 "If the high-speed memory is to operate at a cycle time in the 100-nanosecond region, the class of storage elements that can be used is somewhat limited. Storage elements capable of switching speeds compatible with 100-nanosecond cycle times include (a) thin magnetic films of several types, (b) some forms of laminated ferrites, (c) tunnel diodes, and (d) semiconductor flip-flop type devices." (Shively, 1965, p. 637).

6.105 For example, "most forms of thin films and laminated exhibit adequately fast switching times, but the drive current requirements are large and the readout signals small." (Shively, 1965, p. 637).

"The thin film transistor is barely emerging from the laboratory and it may require several years before it becomes a serious contender for integrated-all-transistor-random-access-memories of large capacities." (Rajchman, 1965, p. 126).

"The development of higher-speed conventional memory devices, of cores and thin films, has slowed, and progress with such devices in breaking the hundred nanosecond barrier will probably take some time." (Pyke, 1967, p. 161).

"Thin films appeared to be more hopeful and are certainly an area where extensive research is being carried out. The main problems still appear to be those of production, especially the problem of achieving reproduceability from one film to another." (Fleet, 1965, p. 29).

"The development of Cryogenic memories has reached the point where planes storing several thousand bits can be fabricated with high yield. However, there are still many problems, such as interconnections, cost, data rate, etc., to be solved before considering a mass store large enough to justify the overhead of cryostat and dewar." (Bonn, 1966, p. 1869).

"Key problems in the fabrication of large monolithic memories are reliability (what to do if a bit fails) and the volatility of the monolithic cell (if the power goes off, the information is lost)." (Henle and Hill, 1966, p. 1859).

6.106 Kohn points out, for example, that "at present, such optically addressed memories seem to be capable of storing 10^5 . . . 10^6 bits/sq in. to have about 0.1 μ sec read access time, and one cell can be written in 100 μ sec. Very high voltages for the light switches are required. This appears to be quite unfavorable from a technical point of view; however, an intensive materials research may overcome the weakness of electrooptic effects and lead to more realistic devices." (Kohn, 1965, p. 133).

6.107 "In the subsystems of a large computer, one serious problem is ground plane noise—spurious signals generated by large currents flowing in circuits which have a common ground . . . Another noise nuisance arises when signals have to be coupled from two subsytems which are operating at two widely different voltages. Lumped together, such difficulties are known as the 'interface problem'." (Merryman, 1965, p. 52).

6.108 "Superconductive cryogenic techniques, which were advocated for quick, on-line storage, will probably not become operational because of the high costs of refrigeration." (Van Dam and Michener, 1967, p. 207).

6.109 "The projected 'break-even' capacity, including refrigeration cost, for a cryoelectric memory is approximately 10^7 bits." (Sass et al., 1967, p. 92).

"The cryoelectronic memory is made up of strip lines, which, though interconnected from plane to plane, display low characteristic impedance and high propagation velocity, and require modest peripheral electronics. Therefore, propagation velocity is the only real limit to memory cycle time. Typical cycle time for the 10^8-bit AB system . . . is approximately 1 μs." (Sass et al., 1967, p. 97).

6.110 "The use of small special purpose memories has become prevalent in recent years. The Honeywell H–800 employed a small core memory to permit multiprocessing as far back as 1960." (Nisenoff, 1966, p. 1826).

6.111 "Much interest has recently been shown in the computer art in incorporating a low-cost, mechanically changeable, read-only store in the control section of a central processing unit. Flexibility of organization and compatibility with other systems can be built into a computer that has a readily changeable read-only store. The printed card capacitor Read-only store is one of three technologies selected for the ROS function in System/360." (Haskell, 1966, p. 142).

"The Read Only Store (ROS) memory is a prewired set of micro-instructions generally set up for each specific application. This means that the specifications of the computer may be tailored to suit the specific application of the user. Thus in an application where square root or some other special function must be performed rapidly or repeatedly, such a sequence of operations may be hard wired into the ROS." (Dreyer, 1968, p. 40).

"Micro-steps, the basic instructions of a stored logic computer, permit the programmer to control the operation of all registers at a more basic level than is possible in the conventional computer. Sequences of micro-steps (each of which requires only 400 nsec to perform) are stored in the ROS as 'micro-routines' which are executed much as a conventional subroutine. However, unlike the unalterable commands of the conventional computer, stored micro-routines may be designed by the programmer to form the most efficient combination of basic computer logical operations for a given application. The speed increase available by use of a ROS does not come from faster computing circuits, but from operating instructions built into the hardware for more efficient ordering of gates, flipflops, registers et al. Thus at the outset of each application, tradeoff studies must be made to determine to what extent software may be replaced by hardware through use of the ROS." (Dreyer, 1968, p. 41).

"The implementation of read-only memories as the control element in a computer has significance for maintainability and emulation. Instruction decoders and controls present a difficult problem to the designer. These elements contain no repetitive patterns like those in data paths and arithmetic units. In addition, they have many external connections. A read-only memory can be used to provide these same control signals. It would contain a long list—hundreds or thousands—of microinstructions. Each program microinstruction from the main memory addresses a sequence of microinstructions in the read-only memory. Each microinstruction in the sequence describes the state of the entire machine during its next cycle. The read-only memory divides easily into segments, since its only external connections are the words address inputs and control signal outputs. LSI read-only memories are being offered by several manufacturers." (Hudson, 1968, p. 42).

"If a read only-memory (ROM) module were used to store subroutines, the relative-efficiency of the code would be much less important. ROM modules cost less than one-fifth as much as comparable amounts of main core storage. Use of ROM to 'can' bread and butter subroutines in low-cost hardware provides an effective solution to a particular problem. The main or read/write memory, thus liberated, can be used to provide feasible flexibility for the main program and to incorporate inevitable, unforeseen, jobs that arise during the development and operating life of a computer system. . . .

"One of the most significant aspects of fourth generation computers will be the use of read-only memories. Tradeoffs of hardware for software and/or speed, and/or reliability, will significantly affect computer organization. Advantages to be gained through the use of ROM include (1) increased speed, output signal level and reliability, (2) decreased read-cycle time, operating power, size, weight, and cost, and (3) nonvolatility." (Walter et al., 1968, pp. 51, 54).

"The 'read-only' function includes the storage of indirect accessing schemes, the implementation of logic functions, the storage of microprogrammed instructions, and related applications." (Chapman and Fisher, 1967, p. 371).

"The attractions of a good read-only storage include not only extremely reliable nondestructive readout, but also lower cost." (Pick et al., 1964, p. 27).

"Special hardware functions implemented in the read-only memory of the 70/46 supplement the [address] translation memory. They are used as additional privileged instructions. Among the capabilities they provide are the ability to load or unload all or selected parts of translation memory and to scan translation memory in such a way that only the entries of those pages that have been accessed are stored into main memory." (Oppenheimer and Weizer, 1968, p. 313).

6.112 "A MYRA memory element is a MYRi Aperture ferrite disk which, when accessed, produces sequential trains of logic-level pulses upon 64 or more otherwise isolated wires . . . A picoprogrammed system, then, consists essentially of an arithmetic section and a modified MYRA memory. A macroinstruction merely addresses an element in the MYRA memory; when the element is accessed, it produces the gating signals which cause the arithmetic unit to perform the desired functions. In addition, it provides gating pulses which fetch the operand (if needed), increment the control counter, and fetch the next instruction." (Briley, 1965, p. 94).

"Picoprogramming is realized by the use of the MYRi–Aperture (MYRA) element, a multiaperture ferrite device which is the basic building block of the instruction mode. Each instruction module is a complete entity and is fabricated on a conventional printed wiring card that can be inserted in a conventional PC connector. Incorporation of a new instruction in the computer or alteration of an existing one is accomplished by the addition or substitution of the appropriate instruction module card." (Valassis, 1967, p. 611).

6.113 "With this GaAs diode array system a very fast, medium capacity, read-only memory with changeable contents becomes realizable. Since many of the existing third generation computers contain microinstructions in read-only stores of about the same capacity as that indicated for the diode-accessed holographic memory, it would seem that the existing read-only memories could be replaced by this type of holographic memory; such a system could be an order of magnitude faster and allow for increased flexibility of CPU configuration by easy change of the microinstruction repertoire." (Vilkomerson et al., 1968, p. 1198).

6.14 In general, these terms are interchangable. Some typical definitions are as follows: "Basically an associative memory involves sufficient logical capability to permit all memory locations to be searched essentially simultaneously–i.e., within some specified memory cycle time . . . Searches may be made on the basis of equality, greater-than-or-equal-to, less-than-or-equal-to, between limits, and in some cases more complex criteria." (Hobbs, 1966, p. 41).

"An associative memory which permits the specification of any arbitrary bit pattern as the basis for the extraction of the record within which this pattern appears is called a *fully associative memory*." (McDermid and Petersen, 1961, p. 59).

"The content-addressable memory (CAM) was initially proposed by Slade as a cryogenic device . . . For this type of memory, word cells are accessed by the character of stored data rather than by physical location of the word cell. The character of data is evaluated in parallel throughout the memory. A common addressing characteristic is equality of stored data and some externally presented key. Memories of this type have also been called associative since a part of the cell contents may be used to call other cells in an 'associative' chain." (Fuller, 1963, p. 2).

"An associative memory is a storage device that permits retrieval of a record stored within by referring to the contents or description rather than the relative address within the memory." (Prywes, 1965, p. 3).

"The distinguishing feature of an associative memory is that it has no explicit addresses. Any reference to information stored in an associative memory is made by specifying the contents of a part of a cell. All cells in the memory which meet the specification are referred to by the statement." (Feldman, 1965, p. 1).

"We have described here an iterative cell which can be used as a content addressable memory from which an entry may be retrieved by knowing part of its contents." (Gaines and Lee, 1965, p. 74).

"Memory systems which retrieve information on the basis of a given characteristic rather than by physical location . . . are called 'content-addressed', 'catalog', or 'associative'. In these types of memory systems, an interrogation word . . . is presented to the memory and a parallel search of all words within the memory is conducted. Those stored words which have a prescribed relationship (e.g., equal to, nearest to, greater than, etc.) to the interrogation word are tagged. Subsequently, the multiple tagged words or responses are retrieved by some interrogation routine." (Miller, 1964, p. 614).

"Associative Memories. An associative memory is a collection of storage cells that are accessed simultaneously on the basis of content rather than location. The ability to associate with circuit logic those cells with similar contents achieves a hardware implementation of an associatively linked or indexed file. Sufficient quantitative results have not yet been developed to establish conclusively the merits of the hardware implementation as against software associative systems. A comprehensive study of hardware associative memory systems given by Hanlon should be read by those interested in this growing technology." (Minker and Sable, 1967, p. 129.)

6.115 "It is extremely unlikely that large fast associative stores will become practicable in the near future . . . We cannot expect associative stores to contribute to a solution of our problems other than in very small sizes to carry out special tasks, e.g., the page register addresses in Atlas." (Scarrott, 1965, pp. 137–138).

"The concept of the content-addressable memory has been a popular one for study in recent years, but relatively few real systems have used content-addressable memories successfully. This has been partly for economic reasons–the cost of early designs of content-addressable memories has been very high–and partly because it is a difficult problem to embed a content-addressable memory into a processing system to increase system effectiveness for a large class of problems." (Stone, 1968, p. 949).

"Considerations of cost make it impossible for the associative memory to contain many registers, and the number that has been adopted in current designs is eight. Unless the associative memory has very recently been cleared, it will be necessary to suppress an item of information in order to make room for a new one; the obvious thing is to suppress the item that has been there for the longest period of time, but other algorithms slightly cheaper to implement have also been proposed. It is claimed on the basis of simulations that eight associative registers enable the full procedure of three memory cycles to be shortcircuited on 90% of occasions." (Wilkes, 1967, p. 4).

"In the past, associative or content addressable memories of any significant size have been impractical for widespread use. Relatively small associative memories have been built with various technologies, such as multiaperture ferrite cores, cryotrons, and various thin-film techniques. The logical flexibility of microelectronics now makes at least scratchpad-size associative memories practical." (Hudson, 1968, p. 42).

6.116 "By a slave memory I mean one which automatically accumulates to itself words that come from a slower main memory and keeps them available for subsequent use without it being necessary for the penalty of main memory access to be incurred again. Since the slave memory can only be a fraction of the size of the main memory, words cannot be preserved in it indefinitely, and there must be wired into the system an algorithm by which they are progressively overwritten. In favorable circumstances, however, a good proportion of the words will survive long enough to be used on subsequent occasions and a distinct gain of speed results. The actual gain depends on the statistics of the particular situation.

"Slave memories have recently come into prominence as a way of reducing instruction access time in an otherwise conventional computer. A small, very-high-speed memory of, say, 32 words, accumulates instructions as they are taken out of the main memory. Since instructions often occur in small loops a quite appreciable speeding up can be obtained. . . .

"A number of base registers could be provided and the fast core memory divided into sections, each serving as a slave to a separate program block in the main memory. Such a provision would, in principle, enable short programs belonging to a number of users to remain in the fast memory while some other user was active, being displaced only when the space they occupied was required for some other purpose." (Wilkes, 1965, pp. 270–271).

6.117 "The B8500 scratchpads are implemented by magnetic thin film techniques developed and organized into linear-select memory arrays . . . To realize the high speed access requirement of 45 nanoseconds, the reading function is nondestructive, eliminating the need for a restoring write cycle when data are to be retained unchanged. . . .

"Insertion of new data into the local memories (writing) can be accomplished within the 100-nanosecond clock period of the computer module." (Gluck, 1965, p. 663).

"4 52-bit words can be requested from a memory module and received at a computer module in a total of 1.0 microsecond, or an average of 250 nanoseconds per word." (Gluck, 1965, p. 662).

"The rationale behind the inclusion of local scratchpad memories in the B8500 computer module encompasses . . . the need for buffering of four-fetches of instructions and data in advance of their use, i.e., lookahead. Also important are its uses as storage for intermediate results, as an economical implementation for registers and counters, and for the extension of the push-down stack." (Gluck, 1965, p. 663).

6.118 "A specific application for a CAM is encountered when assembling or compiling programs where it is common to refer to variables, locations and other items in terms of a symbol. The value or information associated with each symbol must be stored somewhere in memory and a table must be made to relate each symbol to its value. As an example, the symbol ABLKR may be assigned the value 5076. The computer may take this information and store the value 5076 at location 1000 for example. Then the first entry in the symbol table will relate the symbol ABLKR to the location 1000 where the value of ABLKR is stored. As more symbols are defined, this symbol table will grow in length." (Rux, 1967, p. 10).

6.119 "Tied in with scratchpad No. 2 is a small 28-word associative memory (19 bits per word) whose use enhances the utilization of the scratchpad memory by providing content addressing as well as the conventional binary coded word addressing capability." (Gluck, 1965, p. 663).

6.120 "Each cell of the memory receives signals from a set of pattern lines and command lines in parallel, and the commands are executed simultaneously in each cell. One of the commands orders each cell to match its contents against the pattern lines. Each cell in which a match occurs sets its match flip-flop and also generates an output signal . . ." (Gaines and Lee, 1965, p. 72).

These investigators describe some of the differences between their proposed system and others, in part as follows: "The memory we describe here is a logical and practical outgrowth of the content addressable distributed logic memory of Lee and Paull. However, there are several significant differences: the inclusion of a 'match' flip-flop and a 'control' flip-flop in each cell of the memory, the addition of a 'mark' line to activate many cells simultaneously, and the control of the propagation of the marking signal. As a consequence of these, the memory has some novel capabilities, among which are the ability to simultaneously shift the contents of a large group of cells, thus opening or closing a gap in the memory, and the ability to simultaneously mark strings of interest in separate parts of the memory.

"By properly manipulating the cell states, simple programs for correcting errors involving missing or extraneous letters, multiple misspellings, etc., can be devised. Furthermore, by using the marking capabilities of the memory, error correction during retrieval can be accomplished on a selected subset of strings which may be located at widely separated parts of the cell memory." (Gaines and Lee, 1965, p. 75).

6.121 This Sylvania development involves the use of automatically preprocessed plastic sheets to affect the performance and logic behavior of a solenoid-transformer array.

"The interrogation, which may consist of a number of descriptors, each containing many bits of information, causes an appropriate group of solenoids to be driven . . . The solenoids interact simultaneously with all enclosed loops on all the data planes, resulting in a simultaneous voltage on the output of each data plane that is the cross-correlation between the driven input solenoids and each individual data plane. The output of each plane is connected to its own detector-driver which tests the output in comparison with all the other data plane outputs to find that output containing the best correlation. Alternatively, the detector-driver can be set to test for some pre-determined threshold." (Pick and Brick, 1963, p. 245).

Brick and Pick (1964) describe "the application of the solenoid array principle to the problem of word recognition, code recognition, and (in a limited sense), associative memory. The proposed device, based entirely on existing experience with a large character recognition cross correlator, is capable of recognizing one of 24,000 individual English words up to 16 letters long. The simultaneous correlation and selection is made in less than 3 µsec. The selection can be made either on a perfect-match or a best-match basis." (Brick and Pick, 1964, p. 57).

"This form of semipermanent memory offers many advantages to computer and memory users. Among these are: a) ease of contents preparation, involving automated punching of inexpensive standardized cards; b) reliability, as a result of few electrical connections, loose mechanical tolerances, and passive components; c) low cost, since the cards are not magnetic and need only a continuous conducting path; and d) high speed, with estimated cycle time below 1 µsec." (Pick et al., 1964, p. 35).

6.122 "A number of associative memory stacks of 120 resistor cards have been constructed, each stack storing 7200 bits, with each card storing one word of 60 bits length." (Lewin et al., 1965, p. 432).

"This paper describes a fixed memory consisting of one or more stacks of paper or plastic cards, each of which contains an interconnected array of printed or silk-screened film resistors. Each card is compatible with conventional key punches, and information is inserted by the punching of a pattern of holes, each of which breaks an appropriate electrical connection. All punched cards in a stack are cheaply and reliably interconnected using a new batch interconnection technique which resembles an injection molding process, using molten low-temperature solder. The circuit which results is a resistor matrix where the information stored is in the form of a connection pattern. The matrix may be operated as a content-addressable or associative memory, so that the entire array can be searched in parallel, and any word or words stored answering a given description can be retrieved in microseconds." (Lewin et al., 1965, p. 428).

6.123 "The study by Dugan was restricted to considering an existing computer environment and the Goodyear Associative Processor (GAP), a 2048-word associative memory with related logic and instructions. A benchmark problem was studied in which the data base exceeded the size of GAP and was stored on disc. The disc-stored data required transfers to the associative processor or the conventional core for further operations. The study concluded that the effectiveness of a small associative processor, such as GAP, for formatted file problems depended upon the interface of the associative processor with the computer system, the logic of the associative processor, and the load/unload characteristics of the memory associated with the problem. The authors showed that embedding the associative processor within the core memory provided the best system. It also provided a facility for performing arithmetic operations on data, which is ordinarily difficult for an associative processor. The study did not show any major advantages in using a system with an associative processor similar to GAP over one without an associative processor. . . .

"Gall utilized the same computer environment as Dugan but investigated a dictionary lookup phase of an automatic abstracting problem. He concludes that incorporating associative memories that do not have the capacity to store the entire data base requires excessive data transfer and cannot compete with conventional systems that employ a pseudo-random mapping of a word onto a storage location and, therefore, can locate a word by content. Randomized addressing is another software simulation of but one of the facilities provided by an associative processor, namely, the so-called 'exact-match' function." (Minker and Sable, 1967, pp. 130–131).

6.124 The Librascope Associative Parallel Processor was developed for use in the extraction of pattern properties and for automatic classification patterns. It is noted in particular that "the parallel search function of associative memories requires that comparison logic be provided at each memory word cell. The APP, by moderate additions to this logic, allows the contents of many cells, selected on the basis of their initial content, to be modified simultaneously through a 'multiwrite' operation." (Fuller and Bird, 1965, p. 108).

Swanson comments as follows: "Fuller, Bird, and Worthy recently described two machines: an associative parallel processor programmed to abstract properties from visual and other patterns and classify the patterns from the properties; and an associative file processor for rapid parallel search of large complex data bases." (1967, p. 38).

6.125 "The ASP machine organization . . . [has as its dominant element] the context-addressed memory . . . [which] stores both ASP data and programs, and . . . provides the capability to identify, in parallel, unknown items (and link labels) by specifying the context of relations in which the unknowns appear . . . . [It] consists of a square array of identical storage cells which are interconnected both globally and locally. Each cell contains both memory and logic circuitry. The memory circuitry stores either an item, link label, or a relation, plus tag bits. The main purpose of the logic circuitry is to perform the comparison operations which are required to implement global searches of the array and local inter-cell communication." (Savitt et al., 1967, p. 95). See also note 5.47.

6.126 "In the earliest associative memories all bits of all the words of the memory were simultaneously compared with a search word; this is called word-parallel search. For such word-parallel search, the memory has to be of the nondestructive-readout (NDRO) type." (Chu, 1965, p. 600).

"Instead of word-parallel search, bit-parallel search has been developed because of its simpler design and because word-parallel search is of less importance in more complex searches. Bit-parallel search (or bit-sequential search) searches one corresponding bit of all words at one time. For a word of 64 bits, a maximum of 64 bit-parallel searches is made in succession; thus, bit-parallel search pays a price in speed . . . [but] the price is a limited one. In a bit-parallel-search associative memory, nondestructive readout property of memory elements is not necessarily required. This paper describes the organization of a destructive-readout associative memory which can be implemented by a special, very high-speed, magnetic-core memory using conventional technology." (Chu, 1965, p. 600).

"Because parallel-search logic is implemented for only one long-word, implementation of several varieties of search logic is practical. In addition to a bit-comparison logic, other logical operations (such as NAND, NOR, AND, OR) can be implemented relatively simply and less expensively." (Chu, 1965, p. 600).

"For these operations [bit count and bit count and store], each bit of the memory short-word may represent an attribute (a property or a characteristic), and the count of attributes is a useful argument for searching closeness in attributes." (Chu, 1965, p. 605).

6.127 "Circulating memories offer an enormous savings in quantities of logic necessary for a CAM since one set of comparison logic can be used to compare the key register with many memory locations. The comparison logic need only monitor the memory's contents as it passes through the circulating system. . . .

"The principle disadvantage of a circulating CAM is speed. At least one circulation time of the memory is required to interrogate the entire memory. In the case of a magnetic drum system, this time would be measured in milliseconds which is much too slow for many applications. However, with the use of glass delay lines, information can be stored at very high rates, 20 MHZ and higher, and short circulation times can store large amounts of data. For example, a 100 microsecond delay line at 20 MHZ can store 2,000 bits of information. Thus 32 delay lines could store 2,000 words of 32 bits each and this memory could be searched in 100 μsec." (Rux, 1967, p. 2).

6.128 "A goal in designing and interfacing the associative mapping device into the System/360, Model 40, was to introduce no time degradation in the critical main memory address path. We have accomplished this goal by designing the hardware to perform this address translation function in 220 ns. This interrogate time through the associative memory is approximately 50 ns and the remaining time is spent in wire delay and conventional logic, such as the encode circuit which was designed using the 30-ns IBM SLT family. . . .

"The technology used to implement the associative mapping device is the IBM SLT technology. Four special circuits were designed for the associative memory array. They are the associative memory cell used for storing one bit of information, the bit driver, the word driver, and the common sense amplifier used for sensing a mismatch signal in the word direction or a binary 'one' signal in the bit direction." (Lindquist, et al., 1966, p. 1777).

"The mapping device which provides the dynamic storage allocation function in the time-shared system is a 64-word, 16 bit per word, associative memory." (Lindquist et al., 1966, p. 1776).

". . . The Univac 128-word by 36 bit-per-word, 600-nsec scratch pad memory." (Pugh et al., 1967, p. 169).

"The memory . . . utilizes a plated-wire (Rod) memory device operating in a 512-word 36 bit per word memory system. The DRO mode is employed and operation at a 100-nanosecond read-write cycle time is achieved." (Kaufman et al., 1966, p. 293).

"The memory is word-organized with a capacity of 64 words each 24 bits long. Cycle time is approximately 250 nanoseconds. Such memories are suitable for use as 'scratchpads' operating within the central processor or input-output control systems of a computer." (Bialer et al., 1965, p. 109).

"All of the memory circuits — approximately 100 chips — plus 1,536 bits of thin-film magnetic storage and the thin-film interconnection wiring are on a glass substrate measuring 3 by 4-1/2 by 1/10 inches. The circuits occupy about half the substrate area. The extremely small physical size of the memory, the shorter signal paths, the elimination of redundant connections, which packaged circuits would have required, all contribute to an improvement in system speed. . . .

"The 64-word memory has a cycle time of about 250 nanoseconds . . . Plans are to build a 256-word memory that is equally fast and expectations are that eventually 50-nanosecond memories can be built with similar design and fabrication methods [i.e., ultrasonic face-down bonding for interconnection of integrated circuit chips with thin-films]." (Bialer et al., 1965, pp. 102–103).

6.129 "The sonic film memory represents a novel approach to the storage of digital information. Thin magnetic films and scanning strain waves are combined to realize a memory in which information is stored serially. The remanent property of magnetic films is used for nonvolatile storage. The effect of strain waves on magnetic films is used to obtain serial accessing. This effect is also used to derive a nondestructive read signal for interrogation." (Weinstein et al., 1966, p. 333).

6.130 "The new [tunnel diode] memory system contains 64 words of 48 bits each, and test results from a partially-populated cross-sectional model indicate a complete READ/RESTORE or a CLEAR/WRITE cycle time of less than 25 nanoseconds." (Crawford et al., 1965, p. 627).

6.131 "The basic cell employs a thick magnetic film as the high-speed sensing element to sense the information which is stored as a pattern of magnets on a card. Since the magnet card is separate from the array, the latter can be permanently laminated or sealed and the information can be changed very simply and reliably. The advantages of this system stem from a combination of several important features, namely card changeability, high speed, wide mechanical and electrical tolerances, and a linear drive-sense relationship which results in a wide range of operating levels.

"Circuit costs can be minimized by using low-level drivers, giving an additional increase in speed with only a minor increase in sense circuitry . . . For a memory containing four arrays of 256 words and 288 bits per word, an access and cycle time of 19 and 45 ns respectively was achieved . . ." (Matick et al., 1966, p. 341.)

6.132 These investigators suggest further that "the number of bits of storage can be increased in several ways. A modular approach can be used by connecting 64 × 8 memories in parallel or the memory boards can be redesigned to accept the larger number of bits. The modular approach is particularly applicable to the distribution of small memories of various sizes throughout a large computer. It is possible to construct a 64 × 32 memory using either of the above approaches with a cycle time of approximately 20 nanoseconds." (Catt et al., 1966, p. 330).

6.133 "It has been demonstrated that 1000-bit NiFe film DRO memories with cycle times of 60 nsec and access times of about 30 nsec can be built using existing components. Experience with this model indicates that the design can be extended to allow a significant increase of capacity in a memory having this same cycle time and access time; however, it is felt that to achieve a marked increase in speed will require radical departures from the conventional circuit and array techniques that were employed in the model described here." (Anacker et al., 1966, p. 50).

"IBM has developed a bipolar monolithic IC buffer memory for use on the 360/85 that is faster than any they have previously introduced. Access time to the entire contents of the 2K by 72-bit memory is 40 nsec. The buffer memory is constructed of half-inch square building blocks composed of two silicon chips and their leads and insulation. Each of the chips measures less than an eighth of a square inch and contains 664 components (transistors, diodes, and resistors). Each chip provides 64 distinct but interconnected storage cells. The components involved are so minute that 53,000 can fit into a one square inch area.

"The significance of the microminiaturization is of course little related to 'how many of what fit where.' What IBM gains from this construction is a circuit speed—demonstrated on some experimental chips—that is as fast as 750 picoseconds (trillionths of a second).

"The speed of the buffer memory (which at one time was to be called a 'cache', but that term has apparently been dropped) is not down to the 750 pisec figure, but a 7 nsec/chip read and a 12 nsec/chip write speed isn't bad." (Datamation **15,** No. 4, 193 (Apr. 1969.)

6.134 "Electronic Memories, Inc., demonstrated its NANOMEMORY 650 . . . capacity of 16,384 words of up to 84 bits, and an access time of 300 nsec." (Commun. ACM **9,** No. 6, 468 (June 1966).)

6.135 "The ICM-40, a one μ sec cycle time, 500 nsec access time, core memory, available with capacities from 4K × 6 bits to 16K × 84 bits has been announced by Computer Control Company, Inc." (Commun. ACM **9,** 16 (1966).)

6.136 "International Business Machines Corp. has developed an experimental thin-film computer memory that has a 120-nanosecond cycle time, a 589,824-bit capacity and fits in a frame 68 by 42 by 7 inches—including the electronic circuits for driving and sensing." (Electronics **39,** No. 3, 41 (1966).

6.137 "The memory has a capacity of 8192 words, 72 bits per word, and has a cycle time of 110 nanoseconds and an access time of 67 nanoseconds. The storage devices are miniature ferrite cores, 0.0075 by 0.0123 by 0.0029 inches, and are operated in a two-core-per-bit destructive read-out mode. A planar array geometry with cores resting on a single ground plane is used to control drive line parameters. Device switching speed and bit line recovery are treated as special problems." (Werner et al., 1967, abstract, p. 153).

6.138 "It seems a certainty that plated wire memories will become a very important member in the hierarchy of storage systems to be used in the computers of tomorrow." (McCallister and Chong, 1966, p. 313).

"Both UNIVAC 9200/9300 Systems utilize a new plated-wire memory for internal storage featuring a non-destructive read-out mode and monolithic circuitry." (Commun. ACM **9,** 650 (1966).)

6.139 "Capacity of this memory is 4096 68-bit words (278, 528 bits, to be exact) and it operates with a cycle time of 200 nanoseconds and an access time of 160 nanoseconds. It is a word-organized, random-access memory. The memory element is composed of a pair of planar thin films coupled together and read out destructively." (Meddaugh and Pearson, 1966, p. 281).

6.140 "The operation of this half-microsecond-cycle memory module represents a significant achievement in a program of magnetic thin-film development for computer storage which was begun at these laboratories in 1955. Large numbers of substrates were processed and tested, and memory plane assembly and test are now routine operations.

"Memory frames which contain 20 substrates (15,360 bits) can be assembled without great difficulty . . .

A shorter memory cycle can be made possible by reducing the total sense delay, and by the elimination of the bit recover pulse. The pulse transformers will be replaced by active solid-state devices. A reduction of 150 nsec—50 nsec from a shorter sense delay and 100 nsec from elimination of the bit recover pulse—make a cycle time of 350 nsec, or 3-Mc operation, possible." (Bittman, 1964, p. 105).

"Fabrication, assembly, and operation of these half-microsecond memories has proven that large numbers of reliable film substrates are producible and that the completed memories can compete in both speed and price with the high-speed 2-1/2 D-type core memories. The future for planar films looks very bright—both larger and faster memories are in the design stage. These memories will combine the economic advantages of batch fabrication with the fast switching properties of thin-films." (Jones and Bittmann, 1967, p. 352).

6.141 "Extensive memory research aimed at implementing the inherent 1-ns switching capabilities of thin magnetic films within a system environment has resulted in a cross-sectional 147000-bit capacity film memory model with a nondestructive-READ-cycle time of 20 ns, an access time of 30 ns, and a WRITE-READ time interval of 65 ns. The shortest time interval between addressing of two different word lines is 20 ns." Seitzer, 1967, p. 172).

6.142 "A single layer composite magnetic film is operated in a rotational destructive-read-out mode with two access wires. Each bit is composed of two 2 × 6 mil intersections of the word and digit lines with a density of 12,500 bits/in. Magnetic film structures which provide flux closure in the hard, easy, or both directions were considered by rejected when adequate margins were obtained with the single layer. Although the open structure has fabrication advantages, the closed structures remain of interest for future work." (Raffel et al., 1968, pp. 259–260).

"The access time of the memory from change of address to information output from the buffer flip-flops is about 450 nsec. The largest contribution to this delay is the transient on the sense-line due to group-switch voltage transitions. The circuit-limited cycle time for read-write or clear-write is 600 nsec. Recovery from the digit-pulse transient limits the total cycle time to 1μsec with the digit transient overlapping the group-switch transient." (Raffel et al., 1968, p. 261).

6.143 "The chains are made from copper strips which have been plated with a Ni–Fe film and are used to carry word current. The bit/sense signals are carried in wires which pass through the holes in the 'links' of the chain. The memory element thus formed will operate in a rotational switching mode and can be used for a word-organized memory." (Geldermans et al., 1967, abstract, p. 291).

6.144 "It has been shown that high-speed chain memories can be built in very high-density arrays with minimum electromagnetic interactions. The bit/sense wires can be treated as homogeneous transmission lines with relatively high characteristic impedence (100 Ω) and good signal-to-noise ratios. The word lines are high-impedence strip lines whose inductance is mainly determined by the nonlinear magnetic film. This makes evaluation more difficult, but implies favorable properties for the design of very long lines.

"Based on the analysis of recently plated chains with smaller dimensions and better films, the characteristics of various possible chain memories have been extrapolated. Straightforward design philosophy, using transistor selection can be applied for a 0.3×10^6-bit NDRO memory, a 10^6-bit, 100-nsec DRO memory, and a 38×10^6-bit 500-nsec DRO memory.

"These performance predictions reflect the merits of a film device with complete flux closure and high-quality oriented films as exhibited in the chain device; they appear quite attractive for their size, speed, and circuitry requirements. Chains imply a simple semi-batch process and combine fast rotational switching properties of oriented films with the larger signal capability of cores." (Abbas et al., 1967, p. 311).

1.145 Further, "the memory under development has a capacity of 10^8 bits. This capacity is achieved by stacking 10^7-bit modules into one unit . . . Each module has its own set of driving circuits and sense amplifiers. This arrangement leads to a fast, random-access memory, readily realizable mechanically; it is justified from the viewpoint of modularity and cost because the electronic circuits are shared by a large number of bits. All modules share one set of auxiliary circuits, which include the address decoders, timing circuits, information registers, and power supply . . .

"The plated wire used is a nondestructive readout (NDRO) element with equal word currents for reading and writing. This property makes it unnecessary to have rewrite circuitry for each stored bit." (Chong et al., 1967, p. 363).

6.146 "Much attention is currently focused on the development of block-oriented random-access memories. One prospect is the magnetosonic delay-line memory which employs magnetic storage and block-access by semiconductor electronics (to cause the propagation of a sonic wave in the selected line). Nondestructive read-out is derived on the digit lines in sequence by the propagation sonic wave, and write-in is carried out by the coincidence of digit currents and the propagating wave. Another prospect is the opto-electric read-only memory, where the stored information on high resolution photographic plate is block-selected by optical means, employing light-beam deflection or an array of light-emitting elements. The optical readout (of all the bits in the block in parallel) is converted to electric signal by an array of photosensitive elements. Holographic techniques are proposed for the implementation of the high-density photographic processing. The practicality of these block-oriented systems are too early to be realistically appraised." (Lo, 1968, p. 1465).

6.147 For example: "A new mass core memory which offers data access time of 1.5 microseconds and capacity of up to 20 million bits has been placed on the market as a standard product by Ampex Corporation. The RM, which is suitable for use with most large scale computers and data processing systems now in production or use, will be available for delivery early in 1968." (Data Proc. Mag. **10,** No. 1, 58 (Jan. 1968).)

"A randomly-addressable, low cost magnetic mass core memory system with a storage capacity of 0.5 megabytes at a cost of 1 to 2 cents per bit is now available from Ferroxcube's Systems Division. The new memory offers the optimal compromise between cost, bit transfer rate and capacity. It has a full cycle time of 2.5 μs and is capable of operation in ambients to 105° F. The memory system can be organized in word capacities of from 9 to 144 bits (in multiples of 9) per 524-K byte module. Any number of modules can be connected for series or parallel operation to build systems of almost infinite storage capacities. A total of 4.7 million cores are used in the unique 2-1/2 D selection organization, which incorporates an extra wire for sensing the interrogated bits. The total package with all electronics and power supplies measures 72″ × 25″ × 28″." (Computer Design **7,** No. 6, 70 (June 1968).)

"A new, duplex version of the Potter RAM, a magnetic tape random access memory. The new unit has the same performance characteristics as its predecessor, 50.2 million bits of information packed at 1,000 bp; and an average access speed of less than 90 milliseconds." (Commun. ACM **8,** 343–344 (1965).)

"Available in storage capacities up to 32 million bits (1,024,000 words of 32 bits), a new magnetic core memory has a cycle time of less than 4 microseconds. Dependent upon quantity and capacity, the price will be as low as 1-1/2 cents per bit. The Model CM–300 is said to offer true random access at speeds and capacities not previously available in static storage devices. As such, this memory is expected to forge a place in the hierarchy of bulk storage peripherals permitting greater programming flexibility and increased computer throughput. A 2-wire, 2-1/2D magnetics organization and field proven circuitry are utilized to assure high reliability and wide operating margins. All circuits in the system have been subjected to verifiable worst case design. Modular design permits exceptional flexibility in selecting memory interface, ease of maintenance and low logistic support cost. Lockheed Electronics Company, Los Angeles, Cal." (Modern Data Systems **1,** No. 2, 74 (Apr. 1968).)

"The LIBRAFILE 4800 is one of a series of large capacity, high-speed head-per-track disc file memories developed by the Systems Division of Librascope Group. It has a capacity in excess of 400 million data bits, with an average access time of 35 milliseconds. Additional memory modules may be added to increase storage and the head-per-track design permits bit parallel data transfers to meet interface and speed requirements." (Computer Design **7,** No. 6, 22 (June 1968).)

"Laboratory developments completed prior to the initiation of the program described here demonstrated that tape speeds well in excess of 1000 inches per second (ips) and packing densities of one million bits per square inch, with high data reliability, were feasible. Using these developments as a basis, a large memory system could therefore be designed. A prototype 'small' system with a total storage capacity of 10^{11} bits has been built and tested. The following is a description of such a system and its major components.

TBM system description: "The TBM (terabit memory, i.e., 10^{12} bit memory) random access memory uses magnetic tape as a basic storage medium. Random access is provided by using tape search speeds of 1000 ips (compared to approximately 300 ips used on conventional transports) and by using packing densities of 700,000 bits per square inch (compared to approximately 14,000 bits/in. for standard computer tape transports). Data recording is done in the transverse mode (to the direction of tape motion) using rotating heads, the technique used for video recording. A redundant recording scheme permits the achievement of error rates of two errors in 10^{10} information bits. The salient features of the tape transport, permitting this high search speed, and of the recording mode and associated data channels, permitting this high packing density, will be considered in detail following the system description." (Damron et al., 1968, pp. 1381–1382).

"The NCR 353–5 Card Random Access Memory (CRAM) File provides high-speed random or sequential processing of data for NCR 315 computer systems. The data recording is done on magnetic cards 3.65″ x 14″, each containing 144 recording tracks. Each track has a storage capacity of 1,500 6-bit alphanumeric characters. The removable cartridge houses 384 magnetic cards, providing a total storage capacity of 82,944,000 6-bit alphanumeric characters.

"Any card from a cartridge can be dropped to read/write position within 125 milliseconds, providing throughput of 5 cards per second. Data is transferred to the processor at the rate of 50,000 alphanumeric characters per second.

"Up to sixteen CRAM Handlers may be connected to the processor. This provides an online file capacity of over 1,327,104,000 alphanumeric characters (over 1,990,656,000 digits)." (Management Report: MASS RANDOM ACCESS FILES from NCR, nd., p. 1).

6.147a "Enthusiasts of Bell Telephone Labs' recently-patented single-wall domain magnetic memory claim it may some day obsolete the disk. By controlling the magnetic domains, millions of bits can be stored in a diameter less than a micron. The action can actually be seen through a microscope, according to one source.

"Developed by William Schockley, Andrew Bobeck, and H. E. Scoville, the memory works on the spin moments between electrons and the nucleus in a magnetoplumbite material containing rare earth orthoferrites." (Data Proc. Mag. **11**, No. 8, 19 (Aug. 1969).)

6.148 "Magnetic recording bit and track densities, each an order of magnitude higher than those now used, have been demonstrated in the laboratory. Twenty thousand bits per inch and one thousand tracks per inch have been reported. The practical application of these experiments requires considerable development of magnetic heads, recording media, and track location techniques." (Bonn, 1966, p. 1868).

"Ferroxcube Corporation has announced the development of a monocrystalline ferrite material for use in magnetic recording heads. The new material, with its increased wear resistant characteristics, is expected to find wide use in video and high density tape-recording applications where recording head wear is a significant problem. Recording heads made of a new material are expected to increase the head life in these applications by a factor of 10 times or more thereby reducing the service costs of users.

"The practical process for growing single-crystal manganese-zinc ferrite has been developed by using a technique similar to that used in producing synthetic gem stones. This material is not the conventionally designated 'monocrystalline' ferrite, which, though composed of large-size crystals, is actually polycrystalline.

"The single-crystal ferrite, as the name implies, is a single, completely homogeneous crystal, with no grain boundaries to permit crystal pullout which is frequently responsible for the familiar crumbling or wear of the contact face and gap edges. The superior mechanical properties of this new ferrite are further enhanced by proprietary glass-bonding, or metal-bonding processes. Heads fabricated from single-crystal ferrite and bonded by this means present a monolithic contact surface of extremely high density and very low porosity in which the magnetic gap can be controlled to within ± 5 microinches or less and original sharp edges and machined profiles preserved intact through thousands of hours of operation.

"Characteristics include an initial permeability (u_0) of 2250 ± 250 at 100 kHz, 350 ± 50 at 5 MHz." (Comp. Design **8**, No. 1, 30 (Jan. 1969)).

6.149 "There are severe problems in locating and tracking information stored at very high density. Servo-techniques (also being pursued for higher track density in magnetic recording) based upon track-seeking principles are essential for beam scanning approaches." (Hoagand, 1967, p. 259).

6.150 "Adapting videotape recording methods to computer systems may increase the capacity of bulk, random access computer memories a thousandfold. According to Dr. William A. Gross, Ampex vice president, an experimental system now in the lab stores 50 billion bits on single 10- by 1/2-inch reels of magnetic tape, or about 1000 times the capacity of reels currently in use. Information can be accessed and transferred in less than 10 seconds.

"A finished memory based on these developments would enable a user to place all of his digital records on line, ready for random access. This would eliminate shelf storage and delays when a disk pack must be located and placed in the system.

"This videotape recorder increases recording density by using four recording and playback heads mounted on a small metal disk that rotates perpendicularly across the moving tape. This rotary head increases tape-to-head speed by six times that of the fastest fixed-head device and enables the recording of tv pictures or, when applied to coded data, increases the density." (Data Proc. Mag. **11**, No. 2, 14 (Feb. 1969).)

6.151 "A light sensitive recording process called Photocharge, uses a photoelectric potential of material in the film to produce images. It was invented by Dr. Joseph Gaynor and Gordon Sewell

[G. E. Advanced Technology Labs.]. Its main advantage lies in the fact that no external electrical charges or fields are required, as in conventional electrophotographic processes.

"Light and heat alone produce a completely developed picture which consists of minute deformations on the surface of the film.

"Recorded images can be erased by reheating the film. It is then ready to receive and record another picture. . . .

"Since the material is limited in the range of light to which it is sensitive and requires brighter light than conventional film, Dr. Gaynor anticipates that early applications probably will be directed toward memories for graphic and pictorial information and high resolution, inexpensive image reproduction." (Bus. Automation **12**, No. 7, 50 (1965).)

6.152 "A technological development prerequisite to the widespread exploitation of large, multiaccess data-base systems is the large, low-cost, fast random-access mass store. Kuehler & Kerby describe an IBM. 'Photo-Digital' storage device, which is a step in this direction. The article gives no cost information, which makes evaluation difficult, and the long random-access delay is a handicap; the other properties of the device are nevertheless rather exciting. Briefly, a modest configuration can store 10^{12} bits of data, accepting them at a rate of about 0.2 megabits per second and sequentially reading them at a rate of about 1 megabit per second. Random access requires a maximum 3-second delay for acquisition of the proper 'cartridge.' A cartridge is roughly equivalent in capacity to a reel of magnetic tape; the reading rate after acquisition is also roughly equivalent to that of a high-performance tape drive. It would require nearly two months of continuous writing at the maximum rate to fill a 10^{12}-bit configuration." (Mills, 1967, p. 226).

Recent IBM papers describe error detection and correction and data recovery techniques for this system. For example: "In a high-density photo-digital storage system, contamination and other defects can easily obliterate a group of data bits. To operate successfully in spite of this problem in the IBM Photo-Digital Storage System . . . a powerful error-correction code is used . . .

"The problem of effectively implementing a code of this complexity has been solved by a number of innovations. Most important is the use of hardware for encoding, calculation of the power sums, and error detection, while using a control processor, on a time-sharing basis, for error correction. Another important feature is that single-character error correction is tried first; if this is not sufficient, further correction activities can be tried. Other important features are use of a 'trial and recheck' method of error correction, selection of a symmetric code polynomial, use of a table of logarithms for multiplication and division in a Galois field of 64 elements, et cetera." (Oldham et al., 1968, p. 422).

"The chance for error in a line of data read by the world's largest computer storage system is only 0.000075 percent. This statistic is based on test data in 'Error Detection and Correction in a Photo-Digital Memory System,' an article in the November issue of the 'IBM Journal of Research and Development.' The journal article describes the trillion-bit system's error-correction techniques and shows how the system can correct errors rapidly enough for real-time operation. The Photo-Digital Storage System was built by the International Business Machines Corporation under a special contract for the U.S. Atomic Energy Commission. The AEC contract specified the allowable error rate as no more than one 300-bit line with uncorrected errors in 2,700,000 lines read. The system has demonstrated a much better average of one line with uncorrected errors in 13,500,000 lines read. Constructed by the IBM Systems Development Laboratory, San Jose, Calif., the system functions in a network of computers at the Lawrence Radiation Laboratory in Livermore, Calif. A second Photo-Digital System, using the same error-correction techniques and having approximately one-third the storage capacity of the first, has been installed at the Lawrence Radiation Laboratory in Berkeley, Calif." (bema News Bull., Dec. 16, 1968, p. 6).

"The theory of error detection and correction codes is finding its way into practice. With these codes, machines can reconstruct data that have been destroyed. The first practical implementation of a powerful and complex code was achieved in the trillion-bit IBM Photo-Digital Storage System, which uses a Reed-Solomon code for correcting up to 5 error characters in a line of 50 data characters.

"With a correction facility able to correct bursts of errors in a line, a recorded bit need not be larger than the average flaws in the recording medium. In this system flaws cannot be eliminated by pretesting the medium, because the recording is permanent on silver halide photographic film. However, since the film has high resolution, there is a tradeoff between the cost of the correction facility and the cost savings of high-density recording." (Griffith, 1969, p. 456).

6.153 "The principle of the UNICON Computer Mass Memory is derived from the UNICON Coherent Light Data Processing System to create and detect (record and reproduce) information elements in two dimensions by means of signal-modulated coherent laser radiation. . . .

"Continuous readout of the UNICON system utilizes a lightguide surrounding the imaging circle of the rotating objective, carrying the laser radiation transmitted through the unidensity film to a central photomultiplier. Hence, any coherently illuminated information bit is photoelectrically detected within few nanoseconds. . . .

"Width of the information-carrying area of the 16 mm Unidensity film is 8 mm. Information packing density is 6.45×10^8 bits per square inch. Rate of information processing is in the megabits-per-second range. Total capacity of one UNICON memory system is 88×10^9 bits for a 16 mm Unidensity film reel of 100 feet." (Becker, 1966, pp. 711–712).

"The Laser Recording Unit designed and developed by Precision Instrument Company provides a means for reliably and permanently recording and reproducing digital data.

"The Laser Recording Unit uses a new type of permanent recording process which employs a laser to vaporize minute holes in the metallic surface of the recording medium. In this manner digital information is recorded in parallel data tracks along the length of a recording medium strip. The tracks are spaced on the order of five to ten microns (micrometers), center-to-center; each track is composed of bit cells three to five microns in size. For recording or reproducing sequential tracks of digital data, the maximum transfer rate of the Laser Recording Unit is approximately four million bits per second, with an average unrecoverable error rate of one in 10^8 to 10^9 bits, depending on the data density selected.

"The Laser Recording Unit includes a programmable Recorder Control Subsystem which can be designed to provide a hardware and software interface compatible with a specified computer system.

"The major benefits offered by the Laser Recording Unit as a mass digital-data storage unit are summarized below:

(1) Permanent Storage: Data do not degrade over a period of time of the order of years.
(2) Compact Storage: Data are stored at a density approximately 250 times greater than that of digital magnetic tape.
(3) Unlimited Readout: Data can be repeatedly readout for long periods of time without reduction in quality or damage to the record.
(4) Recording Verification: Essentially error-free data records result from the simultaneous read-while-write verification capability that is unique to the laser hole-vaporization method of permanent recording.
(5) Low Error Rates: The average unrecoverable error rate is approximately one in 10^8 to 10^9 bits.
(6) Economical Data Storage: Recording of large quantities of data on the Laser Recording Unit and permanent storage of the data in PI Record Strips significantly decreases the cost-per-bit of recording and storage imposed by existing methods." (McFarland and Hashiguchi, 1968, p. 1369).

See also notes 6.18, 6.19, 6.20.

6.154 "A Photo-Optical Random Access Mass Memory (FM 390) with multibillion bit capacity, announced by Foto-Mem, Inc., can be used to replace or supplement magnetic tape, disk or drum units. Used separately or combined into one system, the FM 390 uses a Photo-Data Card (PDC™) for data storage. Advantages over magnetic storage are in cost and space saving. A typical Foto-Data Cell™ with 100 PDC's stores 3 billion bits of information, allowing a typical installation to hold several trillion bits of data on line." (Data Proc. Mag. **11**, No. 8, 73 (Aug. 1969)).

6.155 "Thin dielectric films which exhibit sustained electronic bombardment induced conductivity (SEBIC) appear to satisfy the control layer requirements for high sensitivity and storage.

"Thin films of cadmium sulfide which exhibit SEBIC were first developed by the Hughes Research Laboratories. . . .

"SEBIC layers can store information in the form of two dimensional conductivity modulations with almost photographic resolution. In addition, they can be excited with brief pulses of high energy electron beams, and they are reusable because they can be erased almost instantaneously. In a sense, they may be thought of as a form of real time photographic film—the principal remaining problem concerns the readout of information." (Lehrer and Ketchpel, 1966, p. 533).

6.156 "This program is devoted to the preparation and investigation of novel kinds of data storage elements of about micron size, and high-density regular arrays thereof, to be addressed with an electron beam of diameter comparable to the element size. Such storage mosaics are formed by developing and adapting appropriate thin-film deposition and micromachining techniques. The latter is based on the use of an electron beam probe to expose an electron-sensitive resist. A storage capacity of about 10^8 bits is believed to be realizable and accessible with an electron beam, without mechanical movement of the storage surface. Currently we are investigating two kinds of elements. The first one is an electrically isolated microcapacitor . . . at the bottom of a hole in a metal-dielectric-metal film sandwich. The other consists of an isolated washer or ring of metal embedded in the dielectric of a multilayer metal and dielectric film sandwich. Ultimately, elements $1/4\mu$ in diameter or smaller, spaced approximately $1/2\mu$ center to center, are expected to be feasible, representing ultimate packing densities up to $4 \times 10^8/\text{cm}^2$." (Rogers and Kelly, 1967, p. 1).

6.157 "The selection of materials and thicknesses for the recording media and substrates is based on obtaining maximum sensitivity to a minimum power density in the recording spot, while maintaining adequate contrast for the readout means selected and stability to the anticipated environment. This basis for selection implies that an increase in the absorption efficiency of the medium is useful only if it leads to a more sensitive media and/or improved contrast. Excellent recording have been achieved at high rates with coatings having less than 20 percent absorption at the laser wavelength. Additional coating and substrate considerations are: adequate adhesion to one another, abrasion resistance, permanency, cost, etc., and special considerations, e.g., the use of a mica substrate to help obtain certain unique properties in the thin films of MnBi which are used for Curie point magnetic recording." (Carlson and Ives, 1968, p. 1).

6.158 "The results of the studies described in this paper have established laser heat-mode recording as a very high resolution real-time recording process capable of using a wide variety of thin film recording media. The best results were obtained with images which are compatible with microscope-type optics. The signals are in electronic form prior to recording and can receive extensive processing before the recording process occurs. In fact, the recordings can be completely generated from electronic input." (Carlson and Ives, 1968, p. 7).

6.159 "Instead of recording a bit as a hole in a card, it is recorded on the file as a grating pattern of a certain spacing . . . A number of different grating patterns with different spacings can be superposed and when light passes through, each grating bends the light its characteristic amount, with the result that the pattern decodes itself . . . The new system allows for larger areas on the film to be used and lessens dust sensitivity and the possibility of dirt and scratch hazards." (Commun. ACM **9**, No. 6, 467 (June 1966)).

6.160 "Both black-and-white and color video recordings have recently been made on magnetic film plated discs. . . .

"Permanent memory systems employing silver-halide film exposed by electron or laser beams. It is possible to record a higher density with beams. Readout at an acceptable error rate is the major problem." (Gross, 1967, p. 5).

"A recently conceived memory which uses optical readout. Instead of recording bits as pulses, bits are recorded as frequencies. An electron beam, intensity modulated with the appropriate frequencies, strikes the electron sensitive silver-halide film moving transverse to the direction of tape motion . . ." (Gross, 1967, p. 8).

"For recording analog information Ampex has focussed efforts on silver-halide film . . . [which] can be made sensitive to either electron or laser beams . . . packing density is an order of magnitude greater than the most dense magnetic recording." (Gross, 1967, p. 6).

"Recent work at Ampex indicates that the Kerr magneto-optic effect is likely to be practical for reading digital information. Recording on a reflective plated tape for magneto-optic reproducing can be done by local heating with a laser or electron beam." [Erasable, potential density 1×10^8]." (Gross, 1967, p. 8).

6.161 "At first glance, machining with electron beams, or adding ions, appear to be suitable for recording digital information. However, problems in obtaining sufficient linearity in the transfer function (the dynamic range and signal-to-noise limits), and accurately positioning the electron beam for reading make it impossible to read out the potential recording density with acceptable error rates. The reduced packing density necessary for acceptable error rates cause these approaches to suffer by comparison with magnetic recording." (Gross, 1967, p. 6).

6.162 "The advantages of electron beams over light are a thousandfold increase in energy density, easy control of intensity and position, and a substantial increase in resolution. To offset these advantages, there are the complications of a demountable vacuum system." (Thornley et al., 1964, p. 36).

6.163 ". . . Some [media] like thermoplastics, involve nearly reversible changes, and the noise content therefore rises with use." (Gross, 1967, p. 2).

6.164 "The standing-wave read-only memory is based on the Lippmann process . . . [in which] a panchromatic photographic emulsion is placed in contact with a metallic mirror . . . Sufficiently coherent light passes normally through the emulsion, reflects from the mirror, and returns through the emulsion. This sets up standing waves with a node at the metallic mirror surface. Developable silver ions form in the regions of the antinodes of the standing wave . . If several anharmonic waves are used to expose the same region of the emulsion, each will set up a separate layer structure . . . Conceivably, *n* color sources spaced appropriately over the band of sensitivity could provide *n* information bits one per color, at each location". (Fleisher et al., 965, p. 1).

Advantage would then be taken of ". . . the Bragg effect, which causes the reflected light to shift to shorter wavelength as the angle of incidence increases . . . With this method, a monochromatic light source, say of violet color, could read out the violet bit at normal incidence and the red bit at the appropriate angle from normal. Hence, a single monochromatic source, such as a laser, could be used to read out all bits . . ." (Fleisher et al., 1965, p. 2).

Further, "random word selection requires a summation of various injection lasers . . . or the use of a white light source in which all colors are present. This source is then deflected to the selected location by the electro-optical deflector. The output from the memory plane is then separated into the various colors by means of a prism or other dispersive medium for a parallel bit readout". (Fleisher et al., 1965, p. 19).

6.165 "A feature of the SWROM [standing-wave read-only memory] which appears to be unique is its capability of storing both digital and video (analog) information. This feature, combined with the capability of the memory for simultaneous, multibit readout with minimal cross talk, will give the SWROM an even wider range of application." (Fleisher et al., 1965, p. 25

6.166 "Parallel word selection . . . could be accomplished by fiber-optic light splitting. It could also be accomplished by flooding the area to be read out with monochromatic light whose frequency is that of the bit or series of bits to be selected. This type of word selection would be useful for associative word selection." (Fleisher et al., 1965, p. 21).

7. Debugging, On-Line Diagnosis, Instrumentation, and Problems of Simulation

7.1 "The quantity and quality of debugging must be faced up to in facility design. This is perhaps the area which has been given more lip service and less attention than any other." (Wagner and Granholm, 1965, p. 284).

"Software checkout still remains an unstructured art and leaves a lot to be desired for the production of perfect code." (Weissman, 1967, p. 31).

"Debugging, regardless of the language used, is one of the most time consuming elements in the software process." (Rich, 1968, p. 34).

"It has been suggested that . . . we are now entering an era in which computer use is 'debugging-limited'." (Evans and Darley, 1966, p. 49).

7.2 "As computing systems increase in size and complexity, it becomes both more important and more difficult to determine precisely what is happening within a computer. The two sorts of performance measurements which are readily available are not very useful; they are the micro-timing information provided by the manufacturer (.4 microseconds/floating add) and the macro-timing information provided by the user ("why does it take three days to get my job back?"). The relationship, if any, between them is obscured by the intricate bulk of the operating system; if it is a multi-programming or time-sharing system, the obscurity is compounded.

"The tools available to the average installation for penetrating this maze are few and inadequate. Simulation is not particularly helpful: the information which is lacking is the very information necessary for the construction of an accurate model. Trace routines interfere excessively with the operation of the system, distorting storage requirements as well as relative timing information. Hardware monitors are not generally available, and though a wondrous future is foreseen for certain of them, they have yet to demonstrate their capabilities in an operational environment; furthermore, they are certain to be too costly for permanent installation, and perhaps too cumbersome for temporary use. The peripheral processor of the Control Data 6000 series computers, however, provides some installations with an easily utilized, programmable hardware monitor for temporary use at no extra cost." (Stevens, 1968, p. C34).

"Without instrumentation, the user is swimming against the tide of history. It is commonly thought that a good programmer naturally achieves at least 80% of the maximum potential efficiency for a program. But while systems have increased greatly in size and complexity, the average expertise of programmers has decreased. In fact, it is axiomatic that virtually any program can be speeded up 25 to 50% without significant redesign! Unless monitored and measured, a program's efficiency may easily be as low as 25%. What is worse, multiprogramming, multiprocessing, real time, and other present-day methods have created such a jumble of interactions and interferences that without instrumentation it would be impossible to know where effort applied for change would yield the best return. One tries to mine the highgrade ore first, while it still exists." (Bemer and Ellison, 1968, p. C40).

7.3 For example, "another practical problem, which is now beginning to loom very large indeed and offers little prospect of a satisfactory solution, is that of checking the correctness of a large program." (Gill, 1965, p. 203).

"With the introduction of time-sharing systems, the conventional tools have become almost worthless. This has forced a reappraisal of debugging procedures. It has become apparent that a new type of debugging tool is needed to handle the special problems created by a time-sharing system. These special problems result from the dynamic character of a time-sharing system—a system in which the program environment is continually changing, a system in which a user is unaware of the actions of other users, a system in which program segments are rolled in and out of storage locations, and a system in which one copy of code can be shared by many users. To debug in this dynamic environment, the programmer needs a debugging support system—a set of debugging programs that operate largely independently from the operating system they service. . . .

"What is needed for time-sharing is a debugging support system that meets the following requirements:

- The system should permit a system programmer at a user terminal to debug system programs associated with his task. When used in this manner, the support system should operate in a time-sliced mode.
- When used to debug a separate task, the support system should provide the facility to modify a system program in relation to that task, without affecting the program as executed in relation to other tasks.
- When a system program bug cannot be located and repaired from a user terminal, the support system should permit a skilled system programmer at a central location to suspend time-sharing activity until the error is located and repaired. The support system should then permit time-sharing activity to be

resumed as though there had been no interruption. The support system should permit a system programmer to monitor the progress of any task from a remote terminal or from the user's terminal.

- The support system should contain the facility to remain dormant until activated by a specified condition. When activated by the condition, the system should be able to gather specified data automatically and then permit processing to continue.
- In its dormant state, the support system should not impact the performance of the parent time-sharing system.
- The support system should use a minimum of main storage and reside primarily on high-speed external storage.
- The support system should be completely independent of the time-sharing system (that is, it must use none of the facilities of the parent system), and it must be simple enough to eliminate any requirement for a support system of its own.

"An effort is currently under way to produce a time-sharing support system that meets these requirements." (Bernstein and Owens, 1968, pp. 7, 9).

"There has been far too little concern on the part of the hardware system designers with the problems of debugging of complex programs. Hardware aids to program debugging would be among the most important hardware aids to software production. On-line debugging is essential. It should be possible to monitor the performance of software on a cathode ray tube console, without interfering with the performance of the software. It should be possible to examine areas of peripheral storage as well as areas of core storage." (Rosen, 1968, p. 1448).

Further, "the error reporting rate from a program system of several million instructions is sufficient to occupy a staff larger than most computing installations possess." (Steel, 1965, p. 233).

7.4 "By *online debugging* we mean program debugging by a programmer in direct communication with a computer (through, typically, a typewriter or teletype), making changes, testing his program, making further changes, etc., all with a reasonably short response time from the computer, until a satisfactory result is achieved." (Evans and Darley, 1965, p. 321).

7.5 "Another area of contact between hardware and debugging is involved with trapping . . . The user may ask for a trap on any combination of a number of conditions, such as a store into a specified register, execution of an instruction at a specified location, or execution of any skip or jump instruction. The debugging program handles the interrupt and reports the relevant information to the user." (Evans and Darley, 1966, p. 44).

It is to be noted that although these authors, as of 1966, were concerned that "very little data seems to exist on the relative efficiency of on-line program debugging versus debugging in a batch-processing mode." (Evans and Darley, 1966, p. 48), by 1968 Sackman et al., could report "on the basis of the concrete results of these experiments, the online conditions resulted in substantially and, by and large, significantly better performance for debug man hours than the offline conditions." (Sackman et al., 1968, p. 8).

7.6 "We have, in general, merely copied the on-line assembly-language debugging aids, rather than design totally new facilities for higher-level languages. We have neither created new graphical formats in which to present the debugging information, nor provided a reasonable means by which users can specify the processing required on any available debugging data.

"These features have been largely ignored because of the difficulty of their implementation. The debugging systems for higher-level languages are much more complex than those for assembly code. They must locate the symbol table, find the beginning and end of source-level statements, and determine some way to extract the dynamic information—needed for debugging—about the program's behavior, which is now hidden in a sequence of machine instructions rather than being the obvious result of one machine instruction. Is it any wonder that, after all this effort merely to create a minimal environment in which to perform on-line higher-level language debugging, little energy remained for creating new debugging aids that would probably require an increased dynamic information-gathering capability.

"EXDAMS (EXtendable Debugging And Monitoring System) is an attempt to break this impasse by providing a single environment in which the users can easily add new on-line debugging aids to the system one-at-a-time without further modifying the source-level compilers, EXDAMS, or their programs to be debugged. It is hoped that EXDAMS will encourage the creation of new methods of debugging by reducing the cost of an attempt sufficiently to make experimentation practical. At the same time, it is similarly hoped that EXDAMS will stimulate interest in the closely related but largely neglected problem of monitoring a program by providing new ways of processing the program's behavioral information and presenting it to the user. Or, as a famous philosopher once almost said, 'Give me a suitable debugging environment and a tool-building facility powerful (and simple) enough, and I will debug the world'." (Balzer, 1969, p. 567).

7.7 "Diagnostics have been almost nonexistent as a part of operating software and very weak as a part of maintenance software. As a result needless time is spent determining the cause of malfunctions; whether they exist in the program, the hardware, the subsets, the facilities or the terminals." (Dantine, 1966, pp. 405–406).

7.8 "Another advantage of computer simulation is that it may enable a system's manager to shrink the anticipated real world life of his system into a relatively short span of simulation time. This capability can provide the manager with a means of examining next week's (month's, year's) production problems this week; thus he can begin to anticipate the points where the operations will require modification. Moreover, he can examine alternative courses of action, prior to their being implemented in the system, to determine which decision is most effective. For example, the manager can increase the processing load in the simulation to determine where the saturation points are. Once these have been determined, he can hold these overloading states constant and vary the other variables (e.g., number of service units, types of devices, methods of operations) to determine how best to increase the system's capacity." (Blunt et al., 1967, p. 76).

Mazzarese (1965) describes the Air Force Cambridge DX–1 system with a "dual computer concept" that permits investigators to change computer logic and configuration in one machine without interference to programs which run on its interconnected mate, especially for study of real time data filtering operations.

7.9 "A technique for servicing time-shared computers without shutting them down has been developed by Jesse T. Quatse, manager of engineering development in the Computation Center at the Carnegie Institute of Technology. The technique is called STROBES, an acronym for shared-time repair of big electronic systems. It includes a test program to exercise the computer, and modified test gear to detect faults in the system." (Electronics **38**, No. 18, 26 (1965)).

7.10 "Diagnostic engineering begins in the initial phases of system design. A maintenance strategy is defined and the system is designed to include features necessary to meet the requirements of this strategy. Special features, known as 'diagnostic handles', are needed for testing the system automatically, and for providing adequate error isolation." (Dent, 1967, p. 100).

"An instantaneous alarm followed by a quick and correct diagnosis in a self-controlling system will limit down-time in many cases to the mere time of repair. Instruments for error detection are unnecessary." (Steinbuch and Piske, 1963, p. 859).

7.11 Further, "when a digital system is partitioned under certain restrictions into subsystems it is possible to achieve self-diagnosis of the system through the mutual diagnosis of its subsystems." (Forbes et al., 1965, p. 1074).

"A *diagnostic subsystem* is that portion of a digital system capable of effectively diagnosing another portion of the digital system. It has been shown that at least two mutually exclusive diagnostic subsystems are needed in self-diagnosable systems." (Forbes et al., 1965, p. 1081).

7.12 "Systems are used to test themselves by generation of diagnostic programs using predefined data sets and by explicit controls permitting degradation of the environment." (Estrin et al., 1967, p. 645).

"The 'Nightwatchman' experiments are directed toward the maintenance problem. Attempts will be made to structure a maintenance concept that will allow for the remote-automatic-checkout of all the computers in the network from a single point. The concept is an extension of the 'FALT' principle mentioned previously. Diagnostic programs will be sent over the lines, during off-use time, to check components, aggregates of components, complete modules, and the entire system. The 'Sentinel' station of the network will be responsible for the gathering of statistical data concerning the data, the queries, the traffic, and the overall operations." (Hoffman, 1965, pp. 98–100.)

"The Sentinel is the very heart of the experimental network. It is charged with the gathering of the information needed for long range planning, the formulation of data automation requirements, and the structuring of prototype systems. In addition to the gathering of statistical data, the sentinel will be the control center for the network, generating priority, policy, and operational details. The responsibility for the observance of security and proprietary procedures will rest with the sentinel station." (Hoffman, 1965, p. 100.)

"This data was taken by a program written to run as part of the CTSS Supervisory Program. The data-taking program was entered each time the Scheduling Algorithm was entered and thus was able to determine the exact time of user state changes." (Scherr, 1965, pp. 27–28).

"Data taken over the summer of 1964 by T. Hastings . . . indicates that the average program accesses (i.e., reads or writes) approximately 1500 disk words per interaction." (Scherr, 1965, p. 29).

"We can and will develop instrumentation which will be automatically inserted at compile time. A user easily will be able to get a plot of the various running times of his program . . ."

Sutherland also refers to a Stanford University program which "plots the depth of a problem tree versus time was used to trace the operation of a Kalah-playing program." (Sutherland, 1965, pp. 12–13).

7.13 "The techniques of fault detection fall into two major categories:

1. *Concurrent diagnosis* by the application of error-detecting codes and special monitoring circuits. Detection occurs while the system is being used.
2. *Periodic diagnosis* using diagnostic hardware and/or programs. Use of the system is interrupted for diagnosis." (Avizienis, 1967, p. [illegible]).

"The four principal techniques of correction are:

1. Correction of errors by the use of error-correcting codes and associated special purpose hardware and/or software (including recomputation).

2. Replacement of the faulty element or system by a stand-by spare.
3. Replacement as above, with subsequent maintenance of the replaced part and its return to the stand-by state.
4. Reorganization of the system into a different fault-free configuration which can continue the specified task." (Avižienis, 1967, p. 734).

"The STAR (*S*elf-*T*esting *a*nd *R*epairing) computer, scheduled to begin experimental operation at the Jet Propulsion Laboratory of the California Institute of Technology this fall, is expected to be one of the first computers with fully automatic self-repair as one of its normal operating functions . . . There are three 'recovery' functions of the STAR computer: (1) detection of faults; (2) recognition of temporary malfunctions and of permanent failures; and (3) module replacement by power switching. The occurrence of a fault is detected by applying an error-detecting code to all instructions and numbers within the computer. Temporary malfunctions are corrected by repeating a part of the program. If the fault persists, the faulty module is replaced." (Avižienis, 1968, p. 13).

7.14 "Diagnostic routines can check the operating of a computer for the following possible malfunctions: a single continuous malfunction, several continuous malfunctions, and intermittent malfunctions. When the test routine finds an error it can transfer program control to an appropriate malfunction isolation subroutine. This type of diagnostic technique is standard and has been well used by the computer industry for large package replacement." (Jacoby, 1959, p. 7–1).

"Needless to say, in order for any malfunction to be isolated by an automatic program, it is necessary for a minimum amount of equipment to function adequately. One of the functions of this minimum equipment includes the ability to sequence from one instruction to another, and to be able to interpret (correctly) and execute at least one transfer of control instruction so that logical choices can be made. The control functions of a computer can be defined as Boolean algebraic expressions of the instantaneous state of the computer. If we state that a line, or path, common to two control statements contains those components that are activated when either of the statements is true, this line is either a factor of both statements or a factor of terms of both statements. Similarly, if we consider circuit elements activated by one but not both of two ways to accomplish the same control function, we have a picture of two terms in the algebraic statement for the control function separated by the connector OR.

"A Boolean term will appear as a circuit which must be active for any statement, of which it is a factor, to be true. Hence the location of circuit malfunctions may be considered from the point of view of isolating the minimal Boolean term involved." (Jacoby, 1959, p. 7–1).

7.15 "A program testing method based on the monitoring of object-program instruction addresses (as opposed to a method dependent on, e.g., the occurrence of particular types of instruction, or the use of particular data addresses) would appear to be the most suitable, because the instruction address is the basic variable of this monitoring technique. Monitoring could be made 'selective' by specifying instruction addresses at which it is to start and stop: to start it at an arbitrary instruction address it is only necessary to replace the instruction located there by the first unconditional interrupt inserted, and similarly when monitoring is to stop and restart later. . . .

"Another use in this field would be to include in the Monitor facilities for simulating any instruction, and to supply it with details of particular instructions suspected of malfunctioning. The Monitor could then stop any program just before one of these instructions was to be obeyed, simulate it, allow the program to execute the same instruction in the normal way, and then compare the results obtained by the normal action and by simulation." (Wetherfield, 1966, p. 165).

"Of course, having achieved the aim of being able to trace in advance the exact course of the object program's instructions, the Monitor is then able to simulate their actions to any desired degree, and it is here that the power of the technique can be exploited. The contents of the store, registers, etc., before the execution of any instruction can be inspected by the Monitor if it temporarily replaces that instruction by an unconditional interrupt." (Wetherfield, 1966, p. 162).

"The monitoring operation can go wrong for any of the following three reasons.

"(l) In the first case one of the planted unconditional interrupt instructions actually overwrites the instruction at which the object program is going to resume (the one at which monitoring started). This would effectively bring things to a standstill since the situation will recur indefinitely. If the rules above have been followed, this situation can only arise when a branching instruction includes itself among its possible destinations, i.e., there is a potential loop stop in the object program. In order to cope with this situation, if it could occur, it may be necessary for the Monitor to simulate the action of the branch instruction completely and make the object program bypass it. The loop stop might still occur, but it would be foreseen.

"(2) The second possible reason for a failure of the monitoring operation occurs if one of the planted instructions overwrites part of the data of the object program, thus affecting the latter's behaviour. This 'data' might be a genuine instruction which is examined, as well as obeyed, by the object program. Alternatively it might be genuine data which happens to be stored in a position which is, by accident or design, a 'redundant' destination of a branching instruction. Both of these dangers can be anticipated by the Monitor, at the cost of a more detailed examination of instructions (to find out which store references by the object program involve a replaced instruction location) and more frequent interrupts.

"The situation savours of 'trick' programming. It is apparent that the monitoring process will be simplified if there is some guarantee that these oddities are absent from object programs." (Wetherfield, 1966, pp. 162–163).

7.16 "MAID (Monroe Automatic Internal Diagnosis) is a program that tells a machine how to measure its circuitry and test performance on sample problems—computer hypochondria." (Whiteman, 1966, p. 67).

7.17 "I have used a program which interprets the program under test and makes a plot of the memory address of the instruction being executed versus time. Such a plot shows the time the program spends doing its various jobs. In one case, it showed me an error which caused a loss of time in a program which nevertheless gave correct answers. . . .

"Think of the thousands of dollars saved by tightening up that one most-used program loop. Instrumentation can identify which loop is the most used." (Sutherland, 1965, pp. 12–13).

7.18 "*On-Line Instrumentation* will bring us better understanding of the interplay of the programs and data within the computer. Simple devices and programs to keep track, on-line, of what the computer does will bring us better understanding of what our information reprocessing systems are actually doing." (Sutherland, 1965, p. 9).

7.19 "The process of building a pilot system configuration and then evaluating it, modifying it, and improving it is very costly both in time and money. Another approach is possible. Before he builds the system, the designer should be able to test his concepts on a simulation model of a document retrieval system. One such model for simulating information storage and retrieval systems was designed by Blunt and his co-workers at HRB-Singer, Inc., under a contract with the Office of Naval Research. In this model, the input parameters for the simulation reflects the configuration of the system, the work schedule of the system, the work schedule of the personnel, equipment availability, the likelihood and effect of errors in processing and the location and availability of the system user. Simulation output provides a study of system response time (both delay time and processing time), equipment and personnel work and idle time and the location and size of the data queues. The systems designer can thus vary the inputs, use the model to simulate the interactions among personnel, equipment, and data at each step of the information processing cycle, and then determine the effect on the system response time." (Borko, 1967, p. 55).

7.20 "Simulation is a tool for investigation and, like any tool, is limited to its inherent potential. Moreover, the realization of this potential is dependent upon economics, the craftsmanship of the designer and the ingenuity of the user. Digital simulation can expedite the analysis of a complex system under various stimuli *if* the aggregate can be divided into elements whose performance can be suitably described. If the smallest elements into which we can divide a system are themselves unpredictable (even in a probabilistic sense) digital simulation is not feasible. (Conway, *et al.*, 1959, p. 94). This feasibility test uncovers an important limitation in today's simulation technology with respect to information systems. In many respects some of the more important man-information-system interactions cannot now be described in a formal manner; hence, cannot be characterized for digital simulation. For example, one can calculate the speed and costs of processing an inquiry, but cannot predict if the output will satisfy the user or estimate its impact on his operations.

"This limitation, therefore, (1) restricts simulation applications to examining the more mechanical aspects of data processing, or (2) forces the design engineer to adopt some simplifying assumptions concerning the effects of man's influence on the system. An example of the first point is a data flow simulation examining the rate of data processing without regard to the quality of the types and mixes of equipment and personnel. This capability for examining the resultant effects in varying parameters of the system enable the design engineer to explore more alternatives in less time and at less cost than ever before; e.g., he can develop cost-capability curves for different possible system configurations under both present and anticipated processing needs. Neglecting this aspect of systems analysis has sometimes led to the implementation of a system saturated by later requirements and confronted by an unnecessary high cost for modification or replacement." (Blunt et al., 1967, pp. 75–76).

"To use simulation techniques in evaluating different computer systems, one must be able to specify formally the expected job mix and constraints under which the simulated system must operate, e.g., operating time per week. Equally important, one must carefully select a set of characteristics on which the competing systems will be judged. For different installations the most important characteristics may well be different. Each system under consideration is modelled, simulation runs are executed, and the results are compared on the selected characteristics.

"Unfortunately, the ideal case seldom occurs. Often the available information about the computer system's expected job mix is very limited. Furthermore, it is a well-known fact that an installation's job mix itself may be strongly influenced both qualitatively and quantitatively by the proposed changes in the system. For example, many of the difficulties with early time-sharing systems can be attributed to the changes in user practices caused by the introduction of the system. When statistics on job mix are available, they are often expressed in averages. Yet, it may be most important to simulate a system's performance under extreme conditions. Finally, it is often difficult to show that a simulation is valid—that is, that it actually does simulate the system in question." (Huesmann and Goldberg, 1967, p. 150).

7.21 "The field of information retrieval has been marked by a paucity of mathematical models, and the basis of present operational computer retrieval systems is essentially heuristic in design." (Baker, 1965, p. 150).

"The semantic and linguistic aspects of information retrieval systems also lend themselves poorly to the rigidity of models and model techniques, for which claims often lack empirical support." (Blunt, 1965, p. 105).

7.22 "There are structures which can easily be defined but which present-day mathematics cannot handle because of the limitations of present-day theory." (Hayes, 1963, p. 284).

"Markov models cannot, in general, be used to represent processes where other than random queuing is used." (Scherr, 1965, p. 32).

"Clearly, we need some mathematical models permitting the derivation of methods which will accomplish the desired results and for which criteria of effectiveness can be determined. Such models do not appear often in the literature." (Bryant, 1964, p. 504).

"First, it will be necessary to construct mathematical models of systems in which content, structure, communication, and decision variables all appear. For example, several cost variables are usually included in a typical operations research model. These are either taken as uncontrollable or as controllable only by manipulating such other variables as quantity purchased or produced, time of purchase or production, number and type of facilities, and allocation of jobs to these facilities. These costs, however, are always dependent on human performance, but the relevant variables dealing with personnel, structure, and communication seldom appear in such models. To a large extent this is due to the lack of operational definitions of many of these variables and, consequently, to the absence of suitable measures in terms of which they can be characterized." (Ackoff, 1961, p. 38).

"Mathematical analysis of complex systems is very often impossible; experimentation with actual or pilot systems is costly and time consuming, and the relevant variables are not always subject to control. . . .

"Simulation problems are characterized by being mathematically intractable and having resisted solution by analytic methods. The problems usually involve many variables, many parameters, functions which are not well-behaved mathematically, and random variables. Thus, simulation is a technique of last resort." (Teichroew and Lubin, 1966, p. 724).

"The complex systems generally encountered in the real world do not lend themselves to neat mathematical formulations and in most cases the operations analyst is forced to reduce the problem to simpler terms to make it tractable." (Clapp, 1967, p. 5).

"Admittedly the degree to which identifiable factors can be measured—compared to the influence of unidentifiable factors—does help determine whether or not an approach can be scientific. It acts as a limit on the area where scientfic methods can be applied. Precision in model building is relating to the difficulty of the problem and the state of human knowledge concerning specific techniques and their application." (Kozmetsky and Kircher, 1956, p. 137).

7.23 "There is no guarantee that a model such as latent class analysis, factor analysis, or anything else borrowed from another field will meet the needs of its new context; however this should not dissuade one from investigating such plausible models." (Baker, 1965, p. 150).

"Models must be used but must never be believed. As T. C. Chamberlain said, 'science is the holding of multiple working hypotheses'." (Tukey and Wilk, 1966, p. 697).

7.24 "System simulation or modeling was subsequently proposed as a substitute for deriving test problems and is still generally accepted as such even though its use introduced the new difficulty of determining and building meaningful models." (Davis, 1965, p. 82).

"The biggest problem in simulation modeling, as in all model building, is to retain all 'essential' detail and remove the nonessential features." (Scherr, 1965, p. 109).

"The fundamental problem in simulation of digital networks is that of economically constructing a mathematical model capable of faithfully replicating the real network's behavior in regard to simulation objectives." (Larsen and Mano, 1965, p. 308).

7.25 "At this time, there exists no special-purpose simulation programming language specifically for use with models of digital computer systems. The general-purposes languages, such as SIMSCRIPT, GPSS, etc., all have faults which render them unsuitable for this type of work." (Scherr, 1965, p. 43).

"The invention of an adequate simulation language promises to be the crowbar needed to bring the programming of operating systems to the level of sophistication of algebraic or commercial programming languages." (Perlis, 1965, p. 192).

"The technique of input simulation . . . can be very expensive. The programs necessary to create the simulated inputs are far from trivial and may well constitute a second system larger than the operational system." (Steel, 1965, p. 232).

7.26 "Those programs which require the simulated computer system and job mix to be specified in algebraic or assembly languages have proved useful; but as general computer systems simulation tools, they require too much difficult recording to be completely satisfactory. One way to improve upon this situation has been to use languages specifically designed to simulate systems. Teichroew and Lubin in a recent review have listed more than twenty languages, among them GPSS, SIMSCRIPT, SOL, and CSL. These simulation languages allow the modeller to specify the computer configuration and job mix in a more convenient manner." (Huesmann, and Goldberg, 1967, p. 152).

7.27 "One of the more exotic applications of digital computers is to simulate a digital computer on another entirely different type of computer. Using a simulation program, application programs developed for the first computer, the source computer, may be executed on a second computer, the object computer.

"Simulation obviously provides many advantages in situations where a computer is replaced by a different computer, for which the applications have not yet been programmed. Simulation techniques enable an installation to continue solving problems using existing programs after the new computer has been installed and the old one removed . . .

"Another situation in which simulation is advantageous is during the development of a new computer. Once specifications for the new computer have been established, programming of applications for the computer can proceed in parallel with hardware developments. The use of a simulator in this situation enables the users to debug their applications before the hardware is actually available." (Trimble, 1965, p. 18).

"One of the most successful applications of the recent microprogramming technology is in the simulation of computers on computers.

"The microprogram control and the set of microprogram routines are in effect a simulation program that simulates the programmer's instruction set on a computer whose instruction set is the set of elementary operations. It may be equally possible to simulate computers with other programmer instruction sets in terms of the same set of elementary operations. This, slightly oversimplified perhaps, is the idea of hardware assisted simulation that is now usually called emulation." (Rosen, 1968, p. 1444).

"As a result of simulation's ability to deal with many details, it is a good tool for studying extensive and complicated computer systems. With simulation, one may assess the interaction of several subsystems, the performances of which are modified by internal feedback loops among the subsystems. For instance, in a teleprocessing system where programs are being read from drum storage and held temporarily in main storage, the number of messages in the processing unit depends upon the drum response time, which depends upon the drum access rate, which, in turn, depends upon the number of messages in main storage. In this case, only a system-wide simulation that includes communication lines, processing unit, and I/O subsystems will determine the impact of varying program priorities on main-storage usage. Studies of this nature can become very time consuming unless parameter selections and variations are carefully limited. It is no small problem to determine which are the major variations that affect the system. In this aspect, simulation is not as convenient as algorithmic methods with which many variations can be tabulated quickly and cheaply." (Seaman, 1966, p. 177).

7.28 "The [SIMSCRIPT] notation is an augmented version of FORTRAN, which is acceptable; but this organization does not take advantage of the modularity of digital systems.

"SIMSCRIPT is an event-based language. That is, the simulation is described, event by event, with small programs, one per event. Each event program (or sub-program) must specify the times for the events following it. Conditional scheduling of an event is extremely difficult." (Scherr, 1965, p. 43).

7.29 Ewards points out that ". . . the preparation of so-called scenarios, or sequences of events to occur as inputs to the simulation, is a major problem, perhaps the most important one, in the design of simulations, especially simulations of information-processing systems." (Edwards, 1965, p. 152).

7.30 "Parallel processes can be rendered sequential, for simulation purpose; difficulties then arise when the processes influence each other, leading perhaps to incompatibilities barring a simultaneous development. Difficulties of this type cannot be avoided, as a matter of principle, and the system is thus not deterministic; the only way out would be to restore determinism through recourse to appropriate priority rules. This approach is justified only if it reflects priorities actually inherent in the system." (Caracciolo di Forino, 1965, p. 18).

7.31 "As a programming language, apart from simulation, SIMULA has extensive list processing facilities and introduces an extended co-routine concept in a high-level language." (Dahl and Nygaard, 1966, p. 671).

7.32 "The LOMUSS model of the Lockheed UNIVAC on-line, time-sharing, remote terminal system simulated two critical periods . . . and provided information upon which the design of the 1108 system configuration was based. An effort is continuing which will monitor the level and characteristics of the workload, equipment utilization, turnaround time, etc., for further model validation." (Hutchinson and Maguire, 1965, pp. 166–167).

"A digital computer is being used to simulate the logic, determine parts values, compute subunit loading, write wiring lists, design logic boards, print checkout charts and maintenance charts. Simulating the logic and computing the loading of subunits gives assurance that a computer design will function properly before the fabrication starts. After the logic equations are simulated, it is a matter of hours until all fabrication information and checkout information is available. Examples are given of the use of these techniques on the design and fabrication of a large scale military computer." (Malbrain, 1959, p. 4–1).

"The new EDP Machine Logic and Control Simulator, LOCS, is designed to facilitate the simulation of data processing systems and logic on the IBM 7090 Data Processing System . . . The inputs of LOCS consist of a description of the machine to be simulated, coded in LOCS language, and a set of test programs coded in either the procedure language of the test problems (e.g., FORTRAN) or in the instruction language of the simulated machine . . . The outputs of LOCS consist of the performance statistics, computation results, and diagnostic data which are relevant to both the test programs and the design of the simulated machine." (Zucker, 1965, pp. 403–404).

7.33 ". . . A system of software and hardware which simulates, with a few exceptions, a multiple set of IBM System/360 computing systems (hardware and software) that are simultaneously available to many users." (Lindquist et al., 1966, p. 1775).

7.34 "Another simulation program designed to simulate multiprocessor systems is being developed by R. Goldstein at Lawrence Radiation Laboratory. Written in SIMTRAN, this program is specifically designed to simulate the OCTOPUS computer system at LRL which includes an IBM 7030 STRETCH, two IBM 7094's, two CDC 6600's, one CDC 3600, two PDP 6's, an IBM 1401, and various I/O devices. A parameterized input table specifies the general multiprocessing configuration, the data transmission rates, memory sizes and buffer sizes. Any other hardware variations and operating system characteristics are introduced with SIMTRAN routines. As output the program produces figures on actual memory utilization, graphs of memory access time, graphs of overhead, graphs of response time, and graphs of several other relevant variables." (Huesmann and Goldberg, 1967, p. 153).

7.35 "One of the more exotic applications of digital computers is to simulate a digital computer on another entirely different type of computer. Using a simulation program, application programs developed for the first computer, the source computer, may be executed on a second computer, the object computer." (Trimble, 1965, p. 18).

7.36 "The flexibility of a digital computer enables one to try out complicated picture processing schemes with a relatively small amount of effort. To facilitate this simulation, a digital picture scanner and cathode-ray tube display was constructed. Pictures were scanned with this system, the signal was recorded on a computer magnetic tape, and this tape was used as input to a program that simulated a picture-transmitting system." (Huang and Tretiak, 1965, pp. 45–46).

"Computer simulation of a letter generator using the above grammar is a comparatively straightforward programming task. Such a program, making use of COMPAX, has been written for CDC 3600 system at the Tata Institute of Fundamental Research, Bombay." (Narasimhan, 1966, p. 171).

At IBM, there has been developed a computer program for image-forming systems simulation (IMSIM/1), so that the photo-optical design engineer can study performance before such systems are actually built (Paris, 1966).

7.37 "The first model developed matches CTSS . . . Next, a simple, first-come, first-served round-robin scheduling procedure will be substituted. Then, a model which incorporates multiprogramming techniques with the CTSS hardware configuration will be developed. Finally, a simple continuous-time Markov model will be used to represent both single-processor and multiple-processor time-shared systems. . . .

"The primary result obtained is that it is possible to successfully model users of interactive computer systems and systems themselves with a good degree of accuracy using relatively simple models." (Scherr, 1965, p. 31).

"The final model to be simulated will represent a system in which swapping and processor operation are overlapped. While a program is being run by the processor, the program which was running previously is dumped and the next program to run is loaded. Since loading and dumping cannot occur simultaneously, there must be room in the core memory for at least two complete user programs—the program being dumped or loaded. Should two programs intended to run in sequence not fit together in the core memory, the processor must be stopped to complete the swapping." (Scherr, 1965, pp. 40–41).

Other examples of experiments in computer simulation of multiple access and time-shared systems include the following: "The development of the simulation program now provides a first-come-first-serve queue unloading strategy. Continuing effort, however, will provide for optional strategies, e.g., selecting the data unit with the shortest servicing time, consideration of what flow will minimize idle time at the central processor etc." (Blunt, 1965, p. 15).

"Project MAC is using a display to show the dynamic activity of jobs within its scheduling algorithm. Watching this display, one can see jobs moving to higher and lower priority queues as time passes." (Sutherland, 1965, p. 13).

7.38 "A great advance also is the wide application of digital computers for the simulation of recognizing and adaptive systems. Digital simulation extraordinarily facilitates and accelerates conducting experiments in this realm by permitting extremely effective experimental investigations without expenditure of materials and with little time spent." (Kovalevsky, 1965, p. 42).

"Third, computer simulation may serve as a heuristic in the search for models. The effort of getting a computer to perform a given task may lead to illuminating psychological hypotheses, even if no behavioral evidence has been taken into account. Moreover, a program which solves problems is by that sole virtue a candidate for a model and deserves the psychologists' attention. After all, proving theorems or recognizing patterns was until recently uniquely human or animal." (Frijda, 1967, p. 59).

Appendix B. Bibliography

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"to foster, serve and promote the nation's economic development and technological advancement"

THE NATIONAL ECONOMIC GOAL

Sustained maximum growth in a free market economy, without inflation, under conditions of full employment and equal opportunity

THE DEPARTMENT OF COMMERCE

The historic mission of the Department is "to foster, promote and develop the foreign and domestic commerce" of the United States. This has evolved, as a result of legislative and administrative additions, to encompass broadly the responsibility to foster, serve and promote the nation's economic development and technological advancement. The Department seeks to fulfill this mission through these activities:

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- **Cabinet Committee on Economic Policy**
- **Urban Affairs Council**
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Promoting progressive business policies and growth.

- **Business and Defense Services Administration**
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Assisting states, communities and individuals toward economic progress.

- **Economic Development Administration**
- **Regional Planning Commissions**
- **Office of Minority Business Enterprise**

Strengthening the international economic position of the United States.

- **Bureau of International Commerce**
- **Office of Foreign Commercial Services**
- **Office of Foreign Direct Investments**
- **United States Travel Service**
- **Maritime Administration**

Assuring effective use and growth of the nation's scientific and technical resources.

- **Environmental Science Services Administration**
- **Patent Office**
- **National Bureau of Standards**
- **Office of Telecommunications**

Acquiring, analyzing and disseminating information concerning the nation and the economy to help achieve increased social and economic benefit.

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